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A NATIONAL
ENVIRONMENTAL QUALITY INDEX
FOR CANADA

TECHNICAL EDITION

A NATIONAL
ENVIRONMENTAL QUALITY INDEX
FOR CANADA
— TECHNICAL EDITION

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A NATIONAL
ECONOMIC QUALITY INDEX
FOR CANADA
- TECHNICAL REPORT -

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A NATIONAL ENVIRONMENTAL QUALITY

INDEX FOR CANADA

INTRODUCTION

What is an Environmental Quality Index?

What is the real state of the Canadian environment? Is it getting better or worse? Are we collecting enough data to be able to answer these questions? Can we devise measures that would reveal conditions across the country?

This publication attempts to answer some of these questions by presenting an Environmental Quality Index for Canada, which may be the first such national index in the world.

Before we can discuss the ramifications of this Index, as well as its limitations, we should attempt to define what we mean by the environment. Perhaps it can be best understood by putting it into a historical context.

For the people who first inhabited Canada, the natural or wild environment was not something to be substantially altered, but the world in which to live and to live off. So it remained for the first Europeans to come here, the fur traders. However, with the coming of later settlers, the situation was different. They had need for permanent occupancy of land for food, fibre and dwellings. The natural environment was in some respects hostile and had to be molded to their needs, and the occupied portions of it became their possession.

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Superimposed on early permanent settlement, other factors have led to substantial modification of the Canadian environment during the past three centuries: widespread use of agriculture and in particular monoculture, the growing of one crop over a large area; increasing use of the forest as a source of raw materials for highly developed forest products industries, and of forest lands and wildlands as a source of mineral wealth; the successive waves of an ever-continuing Industrial Revolution; progressive urbanization, so that now the large majority of Canadians live in or around cities; increased speed and scope of transportation systems, so that every sort of material can be moved from one end of the country to the other in a short time. Obviously, we have not mentioned many of the trends which, over the past few centuries, have increased the potential for man to degrade his environment. Furthermore, we realize that to hold even a short discussion on each of these trends would take a great deal of space.

In very recent years, the "adversary" attitude of the first settlers has become modified towards an attitude of living in some sort of stable relationship with the environment. Difficult as it is to give a definition of the environment, one could be "a description of man's relationships with his natural surroundings". This is a very broad statement. No Index could ever hope to take account of all these relationships, because many are not measured, and others are not even defined carefully enough to be measured. For example, we all know that noise is a form of pollution, but it has been measured only in relatively isolated cases, and in a nonuniform way.

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Similarly, defining the relationship between wildlife and man in such a way that an index can be constructed proved to be a very difficult task indeed, and as a result there is no definitive wildlife index in the present work.

In spite of the fact that we do not know all the relationships between different parts of the environment, we have attempted to show in this Index what we do know or believe, and this knowledge or set of assumptions is implied in each of the sub-indices. For example, in the discussion on air quality, we have some knowledge of the relationship between air pollution and health, and this is implicit in the types of pollutants mentioned and how they are handled mathematically. Similarly, in the section on land environmental quality, we have some idea of the relationship between forest fires and the quality of the forest environment, and this is again implicit in the discussion in that section.

An important point to remember in reading the following pages is that we have considered both positive and negative components of the environment. For example, we discuss both access to parkland (which could be called a positive aspect) as well as water and air pollution (which could be called a negative aspect). In other words, we consider both environmental situations directly attributable to man, and those which come within his perception from time to time, depending on where he lives and what his interests are.

Objectives

At present, most information available on the Canadian environment has been collected for specific purposes and not to give an overall picture. The purpose of this document is to attempt to combine and evaluate this information and to interpret the results to the Canadian public. As well, it tells us what we do and do not know about Canada's environment on a national scale. This is the first step towards identifying those areas where we need more knowledge.

To present what is known in a comprehensive and understandable way, it was decided to express all data in the form of an index. The index was defined as a number, free from units, which ranges from zero, for the best possible environmental condition, to increasing numbers for progressively worse environmental quality. With all data reduced to a unit-free index, several indices may be combined to give an overall picture of environmental quality.

For example, in the chapter on air quality, sulphur dioxide in the air over Canadian cities is not given as so many ounces or grams, but as an index from about 0.5 to about 1.5 for each city. This allowed us to combine the index for sulphur dioxide with that of suspended particulate matter and other pollutants, and finally to calculate an overall air quality index. The use of the index in this way avoids the difficult problem of trying to add ounces or grams of sulphur dioxide to ounces or grams of particulate matter. In other words, by using

indices we don't have to try to add apples and oranges.

Basic Requirements of Data

There are four basic requirements ideally needed to construct such an index.

- (i) all data have to be numerical rather than descriptive.
- (ii) the data have to be both national and comprehensive.
- (iii) the data must, if at all possible, relate to a consistent time period.
- (iv) the data have to be compared with some standard (or status level) for each environmental condition which can be used to transform the data into a unit-free index. This standard could be a national objective, the level at which an environmental situation becomes intolerable, or one chosen on the basis of expert judgement.

Available Environmental Data

Much of the data available today on the Canadian environment does not meet all four basic requirements.

Some data are not numerical and must be put into index form by the appropriate specialists. Many data are not available for every location, or for particular bodies of air, water or land, but still cover the whole country fairly well. Such data are national but not truly comprehensive.

The precise deficiencies will become evident as particular bodies of data are evaluated and put into index form in the following four chapters, but an example occurs in the chapter on air quality, where some pollutants are not measured in certain cities. In water quality, as another example, there are no estimates available on the amounts of pollutants discharged into waterways by a number of industries.

Because of the scarcity of some data, a single base year could not be used for the entire index. In general, though, the information used in the Environmental Quality Index was for 1971. However, in those cases where data for 1971 were not available, older information was used. These instances have been identified in the text.

Problems in Constructing an EQI

A great many assumptions have gone into the construction of this Environmental Quality Index. The detailed qualifications are mentioned in the sections dealing with each sub-index. In this Introduction, it is possible only to list the major problems and assumptions which went into the making of most or all of the sub-indices. As an example, it was difficult to use a consistent status level (or standard) for each environmental condition, because of the different ways data were expressed and the wide variety in environmental aspects which were measured. In general, three methods of compiling indices were used.

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(a) In some cases a standard or objective was used. The numerical value of the environmental condition was divided by the objective to give the index. An index of zero is best (or "perfection"), an index of 1 means the objective is being met, and an index of greater than 1 means that the environmental quality is worse than the objective. (b) In some other cases, the level at which an environmental situation becomes intolerable was used to put the environmental condition in the form of an index. The numerical value was either divided by this "intolerable" condition, or a comparison table was set up. Thus, the index runs between zero for the best (or "perfection") and 1 for the worst. An index greater than 1 is then not possible. (c) In yet other sections of the EQI, it was not possible to set up a national objective or an "intolerable" condition. In this case, the national numerical average of an environmental condition was used as a temporary status level. The particular type of scale used for each sub-index is identified in the text.

For the above reasons, there is therefore a built-in value judgement for each index obtained from an environmental condition. In other words, the actual reading for each condition may be compared with perfection, an objective, an "intolerable" value, or a Canadian average. As our knowledge of man's relationship to his environment grows, we will be better able to harmonize the various mathematical methods we have used in this index.

The term "perfection" is somewhat open to personal interpretation, of course, and each reader may have his own views on the relation-

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ship between the calculated value of the index and the perceived degree of environmental quality in air, water or land.

With no consistent method of reducing data to index form, care should be taken with any value judgement based on the combination of various indices. A value of 1 may mean an intolerable condition for one index, or it may mean an objective being met in another. Similarly, a value for a combined index, like the Air Quality Index or the Water Quality Index, is based only on the data and mathematical methods used for each of the sub-indices which are combined in it, and does not necessarily represent a common environmental state for the whole country. In general, the farther away we get from the original data, the harder it is to assess the overall value of the index we obtain.

It is virtually impossible to reach a value of 0 for some of the sub-indices, no matter what the degree of government or private action. In air, for example, there is always a certain amount of dust and other matter due to winds, active volcanoes in other parts of the world, etc. As a result, the sub-index for suspended particulate matter in air can never become zero. Similar conclusions can be drawn about some other sub-indices, such as those dealing with erosion or turbidity in rivers.

To sum up the discussion of our concept of indices, we stress that it is the use we make of the number that is important, not the actual number itself. For example, the Consumer Price Index,

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issued by Statistics Canada, recently reached the level of 147, but only a few economists were interested in that exact number. What most people were interested in, however, was whether the index was rising or falling, and how fast it was doing so. The EQI must be seen in the same light. As subsequent issues appear, Canadians will be able to see whether environmental quality is improving or deteriorating from year to year. The directions of "good" and "bad" are the same as those for the Consumer Price Index.

The objective of the EQI is to describe environmental phenomena numerically. Whenever possible, though, we have attempted to explain them, realizing that this could only be done completely for some sub-indices. In many cases environmental conditions are influenced by both man-made and natural phenomena. For example, there is a considerable amount of turbidity (cloudiness) in the rivers of the Prairie Provinces, which probably results mostly from natural geological conditions in western Canada. Nevertheless, from an environmental point of view, such information is important and it will be needed to assess the implication of specific water-quality standards for Canadian river basins.

Organization of the EQI

Each of the four chapters dealing with the air, water, land and miscellaneous environmental quality indices, is broken down

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Organization of the EOI

Each of the four chapters dealing with the air, water, land and miscellaneous environmental quality indices, is broken down

into two parts. The first deals with the way the index was computed, and is entitled "Methodology". The second part, entitled "Interpretation", discusses the significance of the calculated total index and of each of the sub-indices. Whenever possible, maps of each of the indices and sub-indices were drawn, to demonstrate their regional and national variability. In all, the present publication contains 00 maps and diagrams.

To show each of the many sub-indices of the EQI for which maps could be prepared clearly, a system of colour coding has been used. In general, the darker the colour on a map, the higher the value of the sub-index shown. In other words, the highest value of a sub-index corresponds to the darkest shade, the next highest to the next lighter shade, and so on. The air quality sub-indices were shown in varying shades of blue, those dealing with water in shades of green, and the land quality sub-indices in shades of brown. It should also be noted that to properly show differences in the maps, the scales vary from one to the other. However, in all cases the value of the sub-index to which a given colour corresponds is shown on the face of the map. To facilitate the use of the maps and diagrams without extensive reference to the text, most have explanatory captions.

A short description of the information that went into the four major indices is now given. As well, a diagram of the overall construction of the EQI is shown in Fig. 11.

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The air quality index is broken down into three major sections, dealing with air quality in urban areas (specific pollutants like sulphur dioxide, oxides of nitrogen, suspended particulate matter, and so on), around these areas (visibility, a measure of air pollution, at airports around cities), and outside major urban areas (industrial emissions in smaller urban areas).

The water quality index was broken down into two major areas. The first pertains to industrial and municipal discharges of wastes into water, and the second with the actual measured water quality and some secondary effects of it. The index concerned with effluent discharges has five sections on different industries and Canadian municipalities. The other index involves turbidity in rivers, mercury levels in fish, and trace metals in municipal water supplies.

In the land quality index, six sub-indices were combined. These included characteristics of forests, overcrowding in Canadian cities, erosion, access to parkland, strip mining and sedimentation.

In the miscellaneous environmental quality index, dealing with those aspects of the environment which do not fit clearly into the three main sectors on air, water and land, sub-indices on pesticides and radioactivity were combined.

It should be noted that most of these sub-indices were themselves made up of sub-sub-indices. For example, the sub-index on forestry had 3 sub-sub-indices.

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Many aspects of the environment were therefore considered in determining and calculating a national EQI. The first index will not, by any means, be the final word on the subject. Lack of data prevented coverage of areas, such as noise, additional aspects of water quality, urban parkland, solid wastes dumped on land, and so on.

As more environmental information become available, some problems of the present EQI methodology described above will be eliminated. Data will be produced with the EQI in mind, sound statistical procedures will be more easily used, and the EQI will be used to manage and improve the environment as well as to describe it. Because parts of future EQI's may be different from parts of this first one, care will have to be taken in comparing the values calculated by each one.

Finally, it should be noted again that the EQI or any index can only explain environmental phenomena in a limited way, or try to relate them to aesthetic perception. The EQI primarily tries to combine measurements of parts of the environment that affect man's health and well-being, and relate them to numerical criteria.

Mathematical Calculations of the Index

We conclude the Introduction with a brief description of the mathematics used. In much of the methodology, a mathematical technique called the "root-mean-square" method has been used to

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combine individual sub-indices. This means that each of the sub-indices to be combined was squared. The squares were then added, and this sum was divided by the number of sub-indices. Then the square root was taken of this number. For example, if three sub-

indices are 0.2, 0.2 and 0.5, their squares are 0.04, 0.04 and 0.25, respectively. The sum of their squares is $0.04 + 0.04 + 0.25 = 0.33$. Dividing by the number of sub-indices, we have $0.33/3 = 0.11$. The square root of this number is then 0.332, which is the root-mean-square" value of the three indices. If we had taken the

arithmetic average of the three indices, we would have had $(0.2 + 0.2 + 0.5)/3 = 0.9/3 = 0.3$. Zero represents the best possible value of the index, and the larger the index, the worse the environmental condition. The root-mean-square method, therefore, is more sensitive to extreme measures of environmental conditions than ordinary averaging. In the example above, the extreme value was 0.5 and the root-mean-square average of 0.332 was closer to 0.5 than the ordinary average of 0.3, and therefore more applicable to our indices than other mathematical techniques.

One other mathematical method that was used to combine sub-indices was that of weighting. By using weights, preference can be given to some sub-indices over others and the final index reflects these preferences. Consider the example above. Suppose the third sub-index (with a value of 0.5) is considered to be twice as important as the other two. Then multiplying the values for the three sub-indices by each of the weights, we get 0.04 ($= 0.2 \times 0.2 \times 1$), 0.04 ($= 0.2 \times 0.2 \times 1$), and 0.5 ($= 0.5 \times 0.5 \times 2$). Then the sum of the squares is $0.04 + 0.04 + 0.5 = 0.58$.

combine individual sub-indices. This means that each of the sub-indices to be combined was squared. The squares were then added, and this sum was divided by the number of sub-indices. Then the square root was taken of this number. For example, if three sub-

indices are 0.2, 0.5 and 0.8, their squares are 0.04, 0.25 and 0.64, respectively. The sum of their squares is $0.04 + 0.25 + 0.64 = 0.93$. Dividing by the number of sub-indices, we have $0.93/3 = 0.31$. The square root of this number is then 0.557, which is the root-mean-square value of the three indices. If we had taken the

arithmetic average of the three indices, we would have had $(0.2 + 0.5 + 0.8)/3 = 0.5$. Zero represents the best possible value of the index, and the larger the index, the worse the environmental condition. The root-mean-square method, therefore, is more sensitive to extreme measures of environmental conditions than ordinary averaging. In the example above, the extreme value was 0.8 and the root-mean-square average of 0.557 was closer to 0.8 than the ordinary average of 0.5, and therefore more applicable to our indices than other mathematical techniques.

One other mathematical method that was used to combine sub-indices was that of weighting. By using weights, preference can be given to some sub-indices over others and the final index reflects these preferences. Consider the example above. Suppose the third sub-index (with a value of 0.8) is considered to be twice as important as the other two. Then multiplying the values for the three sub-indices by each of the weights, we get $0.04 (= 0.2 \times 0.2 \times 1)$, $0.25 (= 0.5 \times 0.5 \times 1)$, and $0.8 (= 0.8 \times 0.8 \times 2)$. Then the sum of the squares is $0.04 + 0.25 + 0.8 = 0.89$.

To combine the root-mean-square technique with weighting, we divide 0.58 not by 3, but by the sum of the weights, which is 4 ($= 1 + 1 + 2$), obtaining 0.145. Taking the square root of this number, we obtain 0.381. Note that because the largest of the three sub-indices (0.5) received the greatest weight, the final answer is closer to it than when each received equal weight, in the first example. The weights used in the EQI were assigned by experts in Environment Canada or selected outside experts under contract to Environment Canada. Details on the experts involved are mentioned in the acknowledgement at the end of this Introduction, and on the last two pages of this publication.

For all the root-mean-square equations used in the EQI, the denominator was the sum of the weights. Then when each of the sub-indices equalled 1 (which, as explained above, could mean equalling an objective, an "intolerable" value, or a Canadian average, depending on the particular sub-index being chosen), the numerator equalled the denominator, and the total combined index was 1 also.

The variations in population density across Canada were often also taken into account by weighting. This was done because many parts of the index describe environmental conditions for people. To do this, indices were weighted according to the population that was likely to be affected. This weighting was done in the same way

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as the weighting for relative importance of indices. For example, suppose three cities of population 100,000, 200,000 and 300,000 had a particular air sub-index of 0.2, 0.4 and 0.6, respectively. If each city had an equal weight, the average index for the three would be $(0.2 + 0.4 + 0.6)/3 = 0.4$. When we weight the cities according to their populations, we get the following table:

TABLE 11

<u>City</u>	<u>Population (P)</u>	<u>Index (I)</u>	<u>P Times I</u>
A	100,000	0.2	20,000
B	200,000	0.4	80,000
C	<u>300,000</u>	<u>0.6</u>	<u>180,000</u>
SUM	600,000		280,000

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Then the average weighted index is: $\frac{280,000}{600,000} = 0.47$.

In other words, the average index is now considerably closer to that of the largest city of the three. This method of weighting was used whenever possible throughout the EQI.

Because there were thousands of calculations made in the compilation of this EQI, they were not shown here. Instead, a series of maps and diagrams were drawn to show the most important points and conclusions. However, all data and detailed calculations are on file at Environment Canada, and will be made available on request. The source of each set of data is mentioned in the text of each chapter.

Summary of Methods

Because of the complexity of the subject, a number of methods were used to construct the EQI. Key among them was the "pyramidal" effect, in which sub-indices were calculated, and then united mathematically into a combined index like that on air or water quality. In the conclusions, these indices are combined further into a tentative total Environmental Quality Index for Canada. Fig. 11, to be discussed in detail shortly, shows this pyramidal effect graphically.

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Another method, referred to above, is that of "preference weighting", in which those sub-indices deemed more important were given more mathematical emphasis. As a rule, it was not possible to use a perfectly consistent criterion for assigning weights throughout the entire EQI. This was again due to the wide diversity of the data and the parts of the total environment they described. However, weights were assigned to particular sub-indices by the experts on the basis of their estimated importance to the total environment. Even among experts, judgements on relative importance can and did differ. The results shown in the EQI are sometimes arrived at by compromise. It is entirely possible that a different set of experts might arrive at a somewhat different set of weights. However, the large majority of the indices in the EQI are not extremely sensitive to the weights chosen. This means that the weights used could generally be altered somewhat without changing the overall conclusions.

It should be mentioned here that it is difficult to make a value judgement on indices calculated by relative weighting from several sub-indices. A weighted average index calculated from several sub-indices, some of which range from zero to 1 and others from zero to any positive value, is hard to relate to an objective, standard or environmental condition. The weighting itself relates only to the estimated relative importance of each sub-index, and not to the actual value calculated for each sub-index.

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involves no value judgement except that the EQI will be related to people whenever possible.

The method of using different types and scales of indices, when necessary, has been discussed above, along with its limitations.

This list comprises the general methods which were used in the construction of the EQI. Although other more specific methods were used in parts of the EQI, they are mentioned in the section on the relevant sub-index.

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In order to tackle the problem of assessing Canada's environmental quality, the Department of the Environment created a special committee to devise methods of describing the state of Canada's environment as accurately as possible. Apart from the members of this committee, over 50 scientists, engineers and administrators were consulted in the compilation of this National Environmental Quality Index. The major contributors are listed on the last two pages of this publication. Although most of the data were available from departmental files, contributions also came from Statistics Canada, the Department of Indian Affairs and Northern Development, the Department of National Health and Welfare, the Department of Energy, Mines and Resources, the Department of Agriculture, the National Research Council, provincial government agencies and agencies in the United States.

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AIR QUALITY INDEX

METHODOLOGY

The Air Quality Index is made up of three parts, and is designed to take account of different aspects of air quality in Canada. The first and most important part is the Index of Specific Pollutants. This index was derived from physical measurements of particular pollutants like sulphur dioxide, carbon monoxide, and so on, in many large urban areas. Details of the quantities measured and the calculations are shown in the next section.

The Index of Specific Pollutants is a measure of air quality in urban areas. In order to derive an Air Quality Index for all of Canada, we need to determine air quality in other areas as well. The air quality around urban areas can be called an Index of Inter-Urban Air Quality. One way of obtaining an index is by calculating the visibility at Canadian airports, which are generally located some distance from the centre of cities. The visibility is a rough measure of the effect on air quality of a number of air pollutants. Another advantage of using this quantity is that the measurements have been carefully standardized over a long period of time.

Finally, we have to consider the air quality in areas far from urban centers, and especially where large industries exist. Some of the pollutants emitted by these industries have a much greater effect on surrounding vegetation, soil, water and wildlife in the countryside than urban emissions. Because physical measurements often are not taken in these areas, an Index of Industrial Emissions

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was calculated. This index is based on estimates of emissions of particular air pollutants.

To produce an overall Air Quality Index, these three indices were combined mathematically with weights assigned by members of the committee.

Because of the different types of data which were combined, the indices are presented in somewhat different types of formats. For examples, where there was a considerable amount of data for maps, contours were drawn for equal values of an index. This procedure was similar to that used in drawing air pressure maps for weather reports. However, the index contours do not imply that every area between two contours (that is, every area of a particular colour) is within the same range of the index. Contours are used to indicate simply and in a general way the places of high and low values of an index. If they had not been used on maps with many data points, the map would have been difficult to read.

For those indices with comparatively few data points, each point was shown separately. These were coloured appropriately to correspond to the value of the index at that point, as denoted in the legend accompanying each map. Again, the fact that each coloured area extends about 40 miles from the centre does not mean that the value of the index is the same for 40 miles from the place where the physical measurements took place, but is shown only to delineate the site clearly.

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Because of the relatively small amount of data for some parts of the Air Quality Index, these data are put into the form of tables. This format is also used because of possible misinterpretation of maps using these data.

Finally, the Index of Industrial Emissions is shown on a province-wide basis, rather than a point-by-point basis, because the effects of this type of emission extends over wide areas. The actual index was calculated on a provincial basis to take account of this.

I Index of Specific Pollutants

An "ideal" index for specific pollutants might be

$$I = \sqrt{\frac{I_{SO_2}^2 + I_{SPM}^2 + I_{CO}^2 + I_{OX}^2 + I_{NO_x}^2}{5}} \quad (A1)$$

where I_{SO_2} is the index for sulphur dioxide, I_{SPM} is the index for suspended particulate matter, I_{CO} is the index for carbon monoxide, I_{OX} is the index for total oxidants, and I_{NO_x} is the index for oxides of nitrogen. Each pollutant in equation (A1) is weighted equally (weight of 1), since each of the components was considered equally important. The denominator is the sum of the weights.

However, this equation has been modified to take account of data and air quality objectives which either were or were not available. Since a large amount of data on the coefficient of haze (COH) has been and is being gathered, it was decided to allot half of the weight for I_{SPM} to the index of COH, I_{COH} . The reason for this is that the

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coefficient of haze is also a measure of the amount of particulate matter in the air. To summarize these conclusions, the index of specific pollutants used is

$$I_{SP} = \sqrt{\frac{I_{SO_2}^2 + \frac{1}{2}I_{SPM}^2 + \frac{1}{2}I_{COH}^2 + I_{CO}^2 + I_{OX}^2 + I_{NO_x}^2}{5}} \quad (A2)$$

For each of these six specific pollutants, objectives (or standards) were chosen. The first four were published by Environment Canada in the Canada Gazette (Part I), on Dec. 16, 1972, and are designed to protect public health and welfare by setting limits on levels of pollution in the air.

(i) Sulphur dioxide. Averaged over one year, 0.02 parts per million (ppm); averaged over 1 day, 0.11 ppm.

(ii) Suspended Particulate Matter: Averaged over one year, 70 micrograms per cubic meter. This standard was to be computed as the geometric mean; for example, if 4 typical readings were 9,3,3, and 1, the geometric mean is

$$\sqrt[4]{9 \times 3 \times 3 \times 1} = \sqrt[4]{81} = 3,$$

where the 4 indicates the fourth root of 81. Averaged over 1 day, 120 micrograms per cubic meter.

(iii) Carbon Monoxide: Averaged over 8 hours, 13 ppm; averaged over 1 hour, 30 ppm.

(iv) Total Oxidants: Averaged over 1 year, 0.015 ppm; averaged over 1 day, 0.025 ppm; averaged over 1 hour, 0.08 ppm.

(v) Coefficient of Haze: Since no objectives have yet been set for this pollutant, the Ontario objectives were adopted. Ontario Regulation 15/70 states that the criteria are 0.45 COH units for a 1 year average, and 1.0 units daily.

(vi) Oxides of Nitrogen: Since no objectives have yet been set for this pollutant, the Ontario objectives were adopted. Ontario Regulation 15/70 states that the criteria are 0.10 ppm averaged over 1 day; 0.20 ppm, averaged over 1 hour.

In terms of availability, the data may be broken down into two groups. The first group are data that have been compiled by the Environmental Protection Service of Environment Canada from 237 sampling instruments in 37 cities (as of Jan 1972). These data include sulphur dioxide, coefficient of haze, and suspended particulate matter. Other data gathered, such as those on dust fall, sulfation rate, and lead, were judged to be either (a) essentially a duplication of one or more of these quantities, (b) included in the Index of Inter-Urban Air Quality, (c) of inadequate reliability, or (d) not pertinent in terms of overall air quality.

The second group comprises measurements on carbon monoxide, total oxidants and oxides of nitrogen. These data are considerably less in volume than that of the first group. The majority of the data are from the same time period (1971) as that of the first group. However, for the sake of completeness some data from previous time periods was also included. This step is valid because the levels of these pollutants generally change slowly with time. The

exact dates of recording of each of the data are on file with Environment Canada.

This second group is less comprehensive in its degree of geographical coverage than the first group. However, because the measurement network for these pollutants will be expanded in the near future, it was decided to include these data. This is also the reason that pollutants in the second group are given the same relative weights as those from the first group in equation (A2). Since the coverage of these indices is relatively small, they were shown in the form of tables, and not maps.

Implicit in the above paragraphs (i) through (vi) are the type of objectives adopted. The question arises because the Dec. 1972 statement set maximum desirable and acceptable objectives for pollutants, in order of increase. It was decided to use, for this first index, the maximum acceptable objectives. The numbers quoted in paragraphs (i) through (iv) were these maximum acceptable objectives. These objectives are designed to provide adequate protection against effects on soil, water, vegetation, etc, and represents the realistic objectives for all parts of Canada. They fit well with the Ontario objective for coefficient of haze and oxides of nitrogen (paragraphs (v) and (vi)), since the objectives chosen were based on a maximum acceptable level (see "Water and Pollution Control", November, 1970, p. 57).

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Because of the nature of the data and the objectives,

each of the indices for the particular pollutant had to be computed differently. In general, the problem was how to take account of the daily (or more frequent) variations in the level of a given pollutant while comparing the annual average to the annual (or other long-term) objective.

The index for suspended particulate matter, I_{SPM} , was calculated as follows:

$$I_{SPM} = \sqrt[n]{C_1 \times C_2 \times C_3 \times \dots \times C_n} \quad (A3)$$

where n is the number of weekly readings per station in a month (there are generally up to 4 or 5), and the C 's are the once a week concentrations of the readings in micrograms per cubic meter. There was no need to take account of the daily objective because the data were available only on a once a week basis. The arithmetic average of the monthly average indices of equation (A3) was taken as the yearly average. The yearly suspended particulate matter indices for each station in a given city were then averaged. Then the city averages were averaged according to the population weighting scheme of Table II. The average index of suspended particulate matter for 1971 was 1.33. A total of 59 stations in 33 cities, with a combined metropolitan population of 11,400,000 were included in the calculations. Results are shown in Fig. A1.

For both sulphur dioxide and coefficient of haze, the indices had to be calculated in a somewhat more complicated manner, since daily as well as yearly objectives existed. Although hourly

objectives exist for sulphur dioxide, no account could be taken of them since the data are not available in this form. In effect, we try to take account of high daily readings separately, as well as averaging them into a yearly average index. There are a number of mathematical methods of doing this. For example, the MITRE Corporation in the United States, as reported in the Third Annual Report (1972) of the U.S. Council on Environmental Quality, used what is called a "Kronecker delta" in combining the daily and yearly objectives:

$$I_{\text{MITRE}} = \sqrt{\left(\frac{C_{a\text{US}}}{S_{a\text{US}}}\right)^2 + \delta_1 \left(\frac{C_{d\text{US}}}{S_{d\text{US}}}\right)^2 + \delta_2 \left(\frac{C_{3\text{US}}}{S_{3\text{US}}}\right)^2} \quad (\text{A4})$$

Here I_{MITRE} is the index for sulphur dioxide. $S_{a\text{US}}$, $S_{d\text{US}}$ and $S_{3\text{US}}$ are the U.S. standards for sulphur dioxide on an annual, daily and 3-hour basis. $C_{a\text{US}}$ is the annual average concentration, $C_{d\text{US}}$ is the maximum daily concentration in the year, and $C_{3\text{US}}$ is the maximum 3-hour concentration in the year. δ_1 and δ_2 are "Kronecker deltas", and the terms containing them are equal to 1 if $C_{d\text{US}}$ or $C_{3\text{US}}$ are greater than $S_{d\text{US}}$ or $S_{3\text{US}}$, respectively, for any one day (or 3-hour period) in the year, and are equal to 0 if this is not the case. The problem with this method was that only the maximum daily (or 3-hour) concentration for the year was used. In other words, only the worst episode was employed, and all others were disregarded for the purposes of equation (A4). This means that

if a city had one extremely high reading of sulphur dioxide in a year, perhaps due to highly unusual weather conditions, it could have a fairly high index. On the other hand, a city whose daily readings approached but never quite exceeded the daily (or 3-hour) standard might have a considerably lower index.

In trying to take account of this problem, and yet give adequate weight to both daily concentrations and annual average concentrations, the following formula was developed:

$$I_{SO_2} = \frac{1}{2} \frac{1}{S_a} \left[C_a + \sqrt{\frac{\sum_{i=1}^n (C_{d_i})^2}{n}} \right] \quad (A5)$$

Here I_{SO_2} is the sulphur dioxide index, C_a is the annual average concentration, S_a is the annual objective (0.02 ppm), C_{d_i} is the daily concentration, and n is the number of readings in a month.

The symbol $\sum$ is a summation sign. In other words, if C_{d_1} , C_{d_2} , C_{d_3} are the daily concentrations, equation (A5) may be

rewritten as

$$I_{SO_2} = \frac{1}{2} \frac{1}{S_a} \left[C_a + \sqrt{\frac{C_{d_1}^2 + C_{d_2}^2 + C_{d_3}^2 + \dots + C_{d_n}^2}{n}} \right] \quad (A6)$$

The first part of the right hand side of equation (A6) indicates what the sulphur dioxide index would have been if there were no daily objective. In other words, in that case we would have had

it is not, and one extremely high reading of sulphur dioxide in a year, compared to the highly unusual weather conditions, it could have a fairly high index. On the other hand, a city whose daily readings approached but never quite exceeded the daily (or 3-hour) standard might have a considerably lower index.

In trying to take account of this problem, and yet give relatively weight to both daily concentrations and annual average concentrations, the following formula was developed:

$$(2) \quad I = \frac{C_A + \left(\frac{C_D}{10} \right)}{1 + \left(\frac{C_D}{10} \right)}$$

where I is the sulphur index, C_A is the annual average

concentration, C_D is the daily average (0.05 ppm) of the

daily concentration, and $\frac{C_D}{10}$ is the index of readings in a year.

The reason for the factor of 10 in the denominator is that

the daily concentration, C_D , is in ppm, and the index may be

calculated as

$$I = \frac{C_A + \left(\frac{C_D}{10} \right)}{1 + \left(\frac{C_D}{10} \right)}$$

The third part of the report (page 10) contains the

list of sulfur dioxide index would have been if there were no daily

objective. In other words, in that case we would have had

$$I_{SO_2} = C_a / S_a \quad (A7)$$

The factor 2 in the denominator of equation (A6) is there to take account of the fact that we are considering two types of concentrations, annual and daily. If it had not been there, then the sulphur dioxide index would have been twice as large as it should have been.

The second part of the right hand side took account of the daily variation in concentration. The root-mean-square method, as included in the term $\sqrt{\sum_{i=1}^n (C_{d_i})^2}$, was used. Here n is the number of readings in a month rather than a year because the data were issued monthly. The basis for using the root-mean-square method was discussed in the Introduction. It was found when numbers were inserted into equation (A6) that the two terms on the right-hand side were approximately of the same size, indicating that annual and daily contributions had about the same weight. The daily objective (0.11 parts per million) was not used in equation (A6) because it was found that no simple combination of this objection with the annual objective would produce an equation which would give approximately equal weight to the annual and daily contributions.

Let's see how this formula works for actual pollutant data. We chose stations 60603 and 60901 for January, 1971. The sulphur dioxide concentrations and calculations are shown in the following Table:

(A7)

$$I_{SO_2} = C_a \sqrt{a}$$

The factor 2 in the denominator of equation (A6) is there to take account of the fact that we are considering two types of concentrations, annual and daily. If it had not been there, then the sulphur dioxide index would have been twice as large as it should have been.

The second part of the right hand side took account of the daily variation in concentration. The root-mean-square method, as included in the term $\sqrt{\frac{1}{n} \sum_{i=1}^n (C_i - \bar{C})^2}$, was used. Here n is the

number of readings in a month rather than a year because the data were issued monthly. The basis for using the root-mean-square method was discussed in the introduction. It was found when numbers were inserted into equation (A6) that the two terms on the right-hand side were approximately of the same size, indicating that annual and daily contributions had about the same weight.

The daily objective (0.11 parts per million) was not used in equation (A6) because it was found that no simple combination of this objective with the annual objective would produce an equation which would give approximately equal weight to the annual and daily contributions.

Let's see how this formula works for actual pollutant data. We chose stations 60503 and 60901 for January, 1971. The sulphur dioxide concentrations and calculations are shown in the following

Table:

TABLE A1

<u>Station</u>	<u>Concentration (parts per million)</u>
60603	0.1, 0.07, 0.14, 0.03, 0.08, 0, 0
	0.03, 0, 0.1, 0, 0.02, 0.03, 0.02
	0, 0, 0, 0, 0, 0, 0.02
	0.01, 0.08, 0.02, 0.07, 0, 0, 0.02
	0.03, 0.01, 0.02
	Sum = 0.81
	<u>n = 31</u>

Squares of Concentrations

0.01, 0.0049, 0.0196, 0.0009, 0.0064, 0, 0
0.0009, 0, 0.0001, 0, 0.0004, 0.0009, 0.0004
0, 0, 0, 0, 0, 0, 0.0004
0.0001, 0.0064, 0.0004, 0.0009, 0, 0, 0.0004
0.0009, 0.0001, 0.0004
Sum = 0.0585

<u>Station</u>	<u>Concentration (parts per million)</u>
60901	0.01, 0.02, 0.02, 0.02, 0.02, 0.03, 0.03
	0.03, 0.03, 0.03, 0.03, 0.02, 0.03, 0.03
	0.02, 0.02, 0.02, 0.02, 0.02, 0.02, 0.03
	0.03, 0.03, 0.03, 0.03, 0.03, 0.02, 0.02
	0.03, 0.02, 0.03
	Sum = 0.77
	<u>n = 31</u>

Squares of Concentrations

0.0001, 0.0004, 0.0004, 0.0004, 0.0004, 0.0009, 0.0009
0.0009, 0.0009, 0.0009, 0.0009, 0.0004, 0.0004, 0.0004
0.0004, 0.0004, 0.0004, 0.0004, 0.0004, 0.0004, 0.0009
0.0009, 0.0009, 0.0009, 0.0009, 0.0009, 0.0004, 0.0004
0.0009, 0.0004, 0.0009
Sum = 0.0201

Substituting these numbers into equation (A6), we have

$$\begin{aligned} I_{SO_2} (60603) &= \frac{1}{2(.02)} \left[\frac{0.81}{31} + \sqrt{\frac{0.0585}{31}} \right] \\ &= \frac{1}{0.04} [0.0261 + 0.0434] = 1.74 \end{aligned}$$

$$\begin{aligned} I_{SO_2} (60901) &= \frac{1}{2(.02)} \left[\frac{0.77}{31} + \sqrt{\frac{0.0201}{31}} \right] \\ &= \frac{1}{0.04} [0.0248 + 0.0255] = 1.26 \end{aligned}$$

The significance of the above calculations is as follows:

both stations had "monthly" indices of almost the same value:

0.0261 and 0.0248. However, station 60603 has a number of "episodes" in which the concentrations exceeded greatly the annual objective of 0.02 ppm, and station 60901 did not. Thus the "daily index" (the second term in the square brackets) for station 60603 was larger by a factor $\frac{0.0434}{0.0255} = 1.70$, i.e., larger by 70%. When we

average both the monthly and daily indices, the total index for station 60603 was larger than that of station 60901 by a factor $\frac{1.74}{1.26} = 1.38$, i.e., larger by 38%.

This shows that by using equation (A6) we took account of both daily and long-term contributions to the sulphur dioxide index, whereas if we had used an equation similar to (A7) we would have missed the daily "episodes".

After the calculation of the monthly index for sulphur

Substituting these numbers into equation (A6), we have

$$I_{SO_2}^{(60603)} = \frac{1}{2} \left[\frac{0.81}{31} + \sqrt{\frac{0.0282}{31}} \right] = \frac{1}{0.04} [0.0261 + 0.0434] = 1.74$$

$$I_{SO_2}^{(60901)} = \frac{1}{2} \left[\frac{0.77}{31} + \sqrt{\frac{0.0201}{31}} \right] = \frac{1}{0.04} [0.0248 + 0.0252] = 1.26$$

The significance of the above calculations is as follows:

both stations had "monthly" indices of almost the same value: 0.0261 and 0.0248. However, station 60603 has a number of "episodes" in which the concentrations exceeded greatly the annual objective of 0.02 ppm, and station 60901 did not. Thus the "daily index" (the second term in the square brackets) for station 60603 was larger by a factor $\frac{0.0434}{0.0252} = 1.70$, i.e., larger by 70%. When we average both the monthly and daily indices, the total index for station 60603 was larger than that of station 60901 by a factor $\frac{1.74}{1.26} = 1.38$, i.e., larger by 38%.

This shows that by using equation (A6) we took account of both daily and long-term contributions to the sulphur dioxide index, whereas if we had used an equation similar to (A7) we would have missed the daily "episodes".

After the calculation of the monthly index for sulphur

dioxide for each station, by equation (A6), the calculation of the total yearly index proceeded in a manner similar to that used for suspended particulate matter. The average sulfur dioxide index I_{SO_2} for 1971 was 1.61. A total of 26 stations in 13 cities, with a combined metropolitan population of 8,260,000, were used in the calculations. Results are shown in Fig. A2.

The coefficient of haze index, I_{COH} , was computed with a formula similar to equation (A6):

$$I_{COH} = \frac{1}{2S_a} \left[C_a + \sqrt{\frac{(C_{d1})^2 + (C_{d2})^2 + (C_{d3})^2 + \dots + (C_{dn})^2}{n}} \right] \quad (A8)$$

where S_a is the annual objectives (0.45 COH units). Other quantities are as described after equation (A6), except that of course the C's refer to the COH concentrations rather than the sulphur dioxide concentrations. The computation proceeds in the same manner as that used with equation (A6). The average coefficient of haze index I_{COH} for 1971 was 1.11. A total of 34 stations in 14 cities, with a combined metropolitan population of 8,780,000, were included in the calculations. Results are shown in Table A2. Although it is difficult to make a comparison on the basis of this table from city to city (for the reasons cited at the head of the table), the data have sufficiently wide coverage with which to compute a national index I_{COH} .

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The coefficient of haze index, I_{COH} , was computed with a

formula similar to equation (A6):

$$(A8) \quad I_{COH} = \frac{1}{S_a} \left[C_a + \sqrt{\frac{(C_1^2 + C_2^2 + \dots + C_n^2)}{n}} \right]$$

where S_a is the annual objective (0.45 COH units). Other quantities are as described after equation (A6), except that of course the C_i refer to the COH concentrations rather than the sulphur dioxide concentrations. The computation proceeds in the same manner as that used with equation (A6). The average coefficient of haze index for 1971 was 1.11. A total of 34 stations in 14 cities, with a combined metropolitan population of 8,780,000, were included in the calculations. Results are shown in Table A3. Although it is difficult to make a comparison on the basis of this table from city to city (for the reasons cited at the head of the table), the data have sufficiently wide coverage with which to compute a national index I_{COH} .

TABLE A2

City-Wide Averages of Index of
Coefficient of Haze (I_{COH})

Note: Caution should be used in the comparison of this Index from one city to another because the exact placement with respect to areas of air pollution of measuring instruments, on whose results this Index is based, varies somewhat from city to city. Furthermore, in the case of coefficient of haze alone, the colour of the particles on which the measurement is based also varies slightly from city to city.

<u>Province</u>	<u>City</u>	<u>Value of Index I_{COH}</u>
Nova Scotia	Glace Bay	0.45
	Sydney	1.47
Quebec	Hull	0.68
	Montreal	1.68
Ontario	Hamilton	1.31
	London	0.47
	Ottawa	0.48
	Sarnia	0.80
	Sudbury	0.57
	Toronto	0.96
	Windsor	1.37
Manitoba	Winnipeg	0.85
Alberta	Calgary	0.54
	Edmonton	0.47

TABLE A2

City-Wide Averages of Index of
Coefficient of Haze (I_{COH})

Note: Caution should be used in the comparison of this Index from one city to another because the exact placement with respect to areas of air pollution of measuring instruments, on whose results this Index is based, varies somewhat from city to city. Furthermore, in the case of coefficient of haze alone, the colour of the particles on which the measurement is based also varies slightly from city to city.

Province	City	Value of Index I_{COH}
Nova Scotia	Glace Bay	0.45
	Sydney	1.47
Quebec	Hull	0.68
	Montreal	1.68
Ontario	Hamilton	1.37
	London	0.47
	Ottawa	0.48
	Sarnia	0.80
	Sudbury	0.57
	Toronto	0.96
	Windsor	1.37
	Winnipeg	0.82
Alberta	Calgary	0.54
	Edmonton	0.47

This concludes the discussion on the first group of pollutants, whose objectives were listed in paragraphs (i), (ii) and (v) above.

Because the three other pollutants in the second group had their data arranged in different ways from those of the first group, the calculation of their indices was done in a slightly different manner.

The index for carbon monoxide is

$$I_{CO} = \frac{1}{2S_8} \left[C_8 + \sqrt{\frac{(C_{1_1})^2 + (C_{1_2})^2 + \dots + (C_{1_n})^2}{n}} \right] \quad (A9)$$

Here S_8 is the 8-hour objective (13 ppm), C_8 is the 8-hour concentration, and $C_{1_1}, C_{1_2}, \dots, C_{1_n}$ are the 1-hour concentrations. Where the 8-hour concentrations were not given, the daily (or in some cases, monthly) average concentrations of carbon monoxide were used instead, since these were regarded as relatively long-term concentrations, as the 8-hour period is.

In equation (A9), n is the number of 1-hour readings in a month or year, depending on the particular set of data. In some cases, however, actual values of the 1-hour concentrations $C_{1_1}, C_{1_2}, \dots, C_{1_n}$ were not given, but were listed in the form of a table of percentiles. This concept means that all the 1-hour concentrations were considered in order of increasing level. If the lowest 10% did not exceed 2 ppm, for example, this quantity was listed under 10% in the table, and so on. Similarly, if 1% of the 1-hour readings for the year equalled or exceeded 10 ppm, the 99th percentile would be 10 ppm. In other words, by converting

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The index for carbon monoxide is

$$I_{CO} = \frac{1}{28} \left[\frac{C_{11}^2 + C_{12}^2 + \dots + C_{1n}^2}{n} + C_{18} \right] \quad (A9)$$

Here C_{18} is the 8-hour objective (13 ppm), C_{18} is the 8-hour concentration, and $C_{11}, C_{12}, \dots, C_{1n}$ are the 1-hour concentrations. Where the

8-hour concentrations were not given, the daily (or in some cases, monthly) average concentrations of carbon monoxide were used instead, since these were regarded as relatively long-term concentrations, as the 8-hour period is.

In equation (A9), n is the number of 1-hour readings in a month or year, depending on the particular set of data. In some cases, however, actual values of the 1-hour concentrations $C_{11}, C_{12}, \dots, C_{1n}$ were not given, but were listed in the form of a table of percentiles. This concept means that all the 1-hour concentrations were considered in order of increasing level. If the lowest 10% did not exceed 2 ppm, for example, this quantity was listed under 10% in the table, and so on. Similarly, if 1% of the 1-hour readings for the year equalled or exceeded 10 ppm, the 99th percentile would be 10 ppm. In other words, by converting

the table of percentiles to the root-mean-square term on the right-hand side of equation (A9), we can take account of "episodes" in the concentration levels. A simple way of accomplishing this is by substituting for the right-hand term of equation (A9) the expression

$$\sqrt{\frac{(p_1 - p_0) \left(\frac{x_1 + x_0}{2} \right)^2 + (p_2 - p_1) \left(\frac{x_2 + x_1}{2} \right)^2 + (p_3 - p_2) \left(\frac{x_3 + x_2}{2} \right)^2 + \dots}{(p_1 - p_0) + (p_2 - p_1) + (p_3 - p_2) + \dots}} \quad (A10)$$

$$= \sqrt{\frac{(p_1 - p_0) \left(\frac{x_1 + x_0}{2} \right)^2 + (p_2 - p_1) \left(\frac{x_2 + x_1}{2} \right)^2 + (p_3 - p_2) \left(\frac{x_3 + x_2}{2} \right)^2 + \dots}{p_n - p_0}}$$

We have the short denominator in (A10) because p_1 cancels with $-p_1$, p_2 with $-p_2$, and so on. In equation (A10), p_0 is the first percentile (always zero), p_1 is the first group of percentiles, p_2 is the second group, up to p_n , which is the final group. Also, x_0 is the value of the concentration for the lowest value (always zero), x_1 is the value of the concentration for the first group, x_2 for the second group, and so on. By using this equation, we preserve the root-mean-square character of the hourly contributions.

The simplest way of illustrating how equation (A10) works is by means of an example. Table A3 shows a typical distribution of concentrations by percentiles.

Table A3

Percentiles	10	30	50	70	90	99
Concentration (ppm)	3.4	4.4	5.3	6.1	7.7	11.5

This table show that the lowest 10% of the 1-hour readings had a maximum value of 3.4 ppm, the lowest 30% had a maximum value of 4.4 ppm, etc. Applying equation (A10), we have

$$= \frac{10(1.7)^2 + 20(3.9)^2 + 20(4.85)^2 + 20(5.7)^2 + 20(6.9)^2 + 9(9.6)^2}{99} = 5.7 \text{ ppm.}$$

This value is substituted for the right-hand term in equation (A9). As with the other specific pollutants, averages were taken of the annual values of I_{CO} for the measuring stations in a city if there was more than one station. A total of 20 stations in 12 cities, with a combined metropolitan population of 8,700,000, were included in the calculation of the national average of I_{CO} . This average, found by the weighting scheme of Table 11, was 0.41. Results are shown in Table A4. Again, while it is difficult to name city-to-city comparisons, the data is adequate to compute the national average.

Table A3

Percentiles	10	30	50	70	90	99
Concentration (ppm)	3.4	4.4	5.3	6.1	7.7	11.5

This table shows that the lowest 10% of the 1-hour readings had a maximum value of 3.4 ppm, the lowest 30% had a maximum value of 4.4 ppm, etc. Applying equation (A10), we have

$$10(1.7)^2 + 20(3.9)^2 + 20(4.85)^2 + 20(5.7)^2 + 20(6.9)^2 + 9(11.5)^2$$

99

= 5.7 ppm.

This value is substituted for the right-hand term in equation (A9). As with the other specific pollutants, averages were taken of the annual values of CO for the measuring stations in a city if there was more than one station. A total of 20 stations in 12 cities, with a combined metropolitan population of 8,700,000, were included in the calculation of the national average of CO . This average, found by the weighting scheme of Table II, was 0.41. Results are shown in Table A4. Again, while it is difficult to make city-to-city comparisons, the data is adequate to compute the national average.

Table 4A

City-Wide Averages of Index of Carbon Monoxide (I_{CO}). The cautionary note at the head of Table A2 also applies to this Table.

Province	City	Value of Index I_{CO}
Quebec	Montreal	0.73
Ontario	Cornwall	0.14
	London	0.13
	Hamilton	0.28
	Ottawa	0.18
	Sarnia	0.27
	Simcoe	0.23
	Sudbury	0.10
	Toronto	0.35
	Windsor	0.45
Alberta	Edmonton	0.11
British Columbia	Vancouver	0.20

The index for total oxidants, I_{OX} , was found from

$$I_{OX} = \frac{1}{2S_a} \left[C_a + \sqrt{\frac{(C_{1_1})^2 + (C_{1_2})^2 + \dots + (C_{1_n})^2}{n}} \right] \quad (A11)$$

where S_a is the annual objective (0.015 ppm), C_a is the annual average concentration, and $C_{1_1}, C_{1_2}, \dots, C_{1_n}$ are the 1-hour concentrations.

Where annual averages C_a were not available and monthly averages were, the latter were averaged arithmetically and substituted for C_a in equation (A11). Both monthly and yearly averages are relatively long-term concentrations, so the average of the former can be compared to the latter. Because daily averages were not available, no use was made of the daily objective (0.025 ppm).

Since some of the data were given in the form of percentiles, the same methodology was used for total oxidants as was used for carbon monoxide, as illustrated in Table A3 and equation (A10). Stations in a given city were averaged to produce a city-wide average. A total of 13 stations in 11 cities, with a combined metropolitan population of 6,400,000, were included in the calculation of the national average of I_{OX} . This average, found by the weighting scheme of Table II, was 1.69. Results are shown in Table A5. The same explanation of the results which was used before Tables A2 and A4 also apply here.

Table 5A

City-Wide Averages of Index of Total Oxidants (I_{OX}). The cautionary note at the head of Table A2 also applies to this table.

<u>Province</u>	<u>City</u>	<u>Value of Index I_{OX}</u>
Ontario	Cornwall	2.19
	Hamilton	2.91
	London	1.53
	Ottawa	1.28
	Sarnia	2.32
	Sudbury	1.49
	Toronto	1.73
	Windsor	1.98
Alberta	Calgary	0.57
	Edmonton	1.51
British Columbia	Vancouver	1.63

Finally, the index for oxides of nitrogen was computed.

The formula is

$$I_{NO_x} = \frac{1}{2} \frac{S_{24}}{C_{24} + \sqrt{\frac{C_{1_1}^2 + C_{1_2}^2 + C_{1_3}^2 + \dots + C_{1_n}^2}{n}}} \quad (A12)$$

Here S_{24} is the daily objective (0.10 ppm), C_{24} is the annual average daily concentration, and $C_{1_1}, C_{1_2}, \dots, C_{1_n}$ are the 1-hour concentrations. As in the computations leading to the indices for carbon monoxide and total oxidants, the percentile formula, equation (A10), was substituted when necessary for the root-mean-square term on the right-hand side of equation (A12). Where monthly or yearly average concentrations were given, these were taken as being equivalent to the 24-hour concentration, for purposes of computation.

As before, stations in a given city were averaged to produce a city-wide average. A total of 15 stations in 11 cities, with a combined metropolitan population of 5,900,000, were included in the calculation of the national average of I_{NO_x} . This average, found by the weighting scheme of Table 11, was 0.63. Results are shown in Table A6. The same explanation of the results which was used before Tables A2, A4 and A5 also apply here.

Table A6

City-Wide Averages of Index of Oxides of Nitrogen (I_{NO_x}). The cautionary note at the head of Table A2 also applies to this table.

Province	City	Value of Index I_{NO_x}
Ontario	Cornwall	0.29
	London	0.36
	Ottawa	0.40
	Sarnia	0.26
	Simcoe	0.18
	Sudbury	0.19
	Toronto	0.76
	Windsor	0.53
Alberta	Calgary	0.47
	Edmonton	0.33
British Columbia	Vancouver	0.83

It should be noted that while the formula for converting percentiles to a root-mean-square average of concentrations, equation (A10), is not a perfect substitute for the actual data on hourly concentrations, the equation produces results close to those found by the root-mean-square method. For example, some data were broken down on both a percentile basis and an hourly basis. The results by equation (A10) were only a few percent higher than the root-mean-square method.

As previously mentioned, although the bulk of the data for the last three pollutants were from 1971, some data from previous years were included to provide continuity.

To produce an overall index of specific pollutants I_{sp} the 6 sub-indices were combined by means of equation (A2). Although more data were available on the first group of 3 pollutants than the second group, all were given equal weight because more data will eventually be available for the second group. The index I_{sp} , compiled from data from 36 cities with a combined metropolitan population of 11,500,000 was 1.23. Because comparatively few cities had data on all 6 pollutants, this result is not shown on a map.

The levels of the indices for specific pollutants not only vary from region to region across Canada, but vary in time as well. The average level for each of the first group of pollutants was calculated for each month of 1971. The weighting scheme for population, as shown in Table II, was used. Results for suspended particulate matter, sulphur dioxide, and coefficient of haze are

shown in Figs. A3, A4 and A5 respectively. Again, this could not be done for the second group of pollutants since in many cases the data were not available in a monthly basis.

II Index of Inter-Urban Air Quality

This index, designed to give an indication of air quality in the regions around urban centres, is based on visibility readings at Canadian airports. This does not preclude the use of other regionally-based data if and when the criteria for inclusion are met, as discussed in the Introduction.

Visibility observations are taken each hour by trained observers at many Canadian airports together with observations on the presence of haze, smoke, precipitation, or dust. These data could be combined in a number of ways: the number of times that airborne particulates like haze, smoke and so on are seen, the sum of the recorded visibilities for each year, etc. Before discussing these points in detail, it should be noted that precipitation alters the visibility; a particular case is heavy snow. Due to these effects, it was decided to exclude each hourly reading in which precipitation was noted.

Furthermore, when haze or smoke are noted, it gives only a qualitative reading of the air pollution. In other words, either haze is there or it is not; the inclusion of that word in a visibility report gives no idea of its severity. Thus the visibility (in miles) gave a more quantitative (or numerical) description of the effect of the pollutants which were in the air.

The quantity chosen to describe the visibility was the actual sum of the visibilities for each hour. For example, if over an 8-hour period the observer could see 5,4,2,1,2,4,6,10 miles for each consecutive hour, the sum of visibilities was 34 miles. Next, we took account of the fact that some airports have longer periods of visibility (without precipitation) than others. This was done by dividing the sum of the visibilities (34 in the example above). For the example, the average visibility was then $34/8 = 4.25$ miles. If rain had occurred in the last hour's reading, the average then would have been $24/7 = 3.43$ miles. In effect, all hourly observations were used, except those in which precipitation occurred.

The data were broken down into day and night readings, and could be computed monthly. For the present purposes only the yearly sum for 1971 was used, employing the average visibility for all 365 days.

In the previous section on specific pollutants, it was seen that standards or objectives were used for each of the specific pollutants. A "standard" for visibility was necessary to compare data from one airport to another on a consistent basis. Since no government standards for average visibilities have been or are likely to be set, the average visibilities at two far northern stations, Yellowknife and Whitehorse, were taken as a baseline measure. It was assumed that because these stations were so small and distant from major sources of urban pollution, they would be little affected by air pollution. The average visibilities for the last 19 years at both airports were averaged to produce the standard of visibility. As an

The quantity chosen to describe the visibility was the actual

sum of the visibilities for each hour. For example, if over an 8-hour

period the observer could see 2.4, 2.1, 2.4, 0.1 miles for each

consecutive hour, the sum of visibilities was 3.0 miles. Next, we

took account of the fact that some airports have longer periods of

visibility without precipitation than others. This was done by

dividing the sum of the visibilities (3.0 in the example above) by

the example, the average visibility was then $3.0/8 = 0.375$ miles.

For each hour, the average visibility was then 0.375 miles. This

value was used in the last hour's reading, the average then would

have been $2.4/7 = 0.343$ miles. In effect, all hourly observations were

averaged, except those in which precipitation occurred.

The data were broken down into day and night readings, and

might be computed monthly. For the present purposes only the

monthly average for 1971 was used, averaging the average visibility for

all 12 months. In the previous section on specific pollutants, it was seen

that standards or objectives were used for each of the specific

pollutants. For visibility, the visibility was necessary to compare

data from one airport to another on a consistent basis. Since no

government standards for average visibilities have been or are likely

to be, the average visibilities at two far northern stations,

Yellowknife and Inuvik, were taken as a baseline measure. It was

assumed that because these stations were so small and distant from

major sources of urban pollution, they would be little affected by

air pollution. The average visibilities for the last 10 years at both

stations were averaged to produce the standard of visibility. An

indication of the quality of this standard, only two cities out of the 37 for which the Environmental Protection Service collects specific pollutant data (Medicine Hat and Lethbridge) had a higher average visibility for 1971 than the average of Whitehorse and Yellowknife.

Since the average visibility at airports was a function of the overall average of air pollutants in the vicinity, the index of visibility had to be approximately numerically comparable to the index I_{sp} derived from the specific pollutant data, described in the last section. It was found after computation that this goal could be accomplished by dividing the visibility index by a factor 2.

The index of inter-urban air quality then became

$$I_{reg} = \frac{V_{fn}}{2V_{ap}}, \quad (A13)$$

where I_{reg} is the index of inter-urban (or regional) air quality, V_{fn} is the average visibility for the two far northern stations, and V_{ap} is the average visibility for 1971 for each airport. It was found that $V_{fn} = 14.6$ (in miles). If a Canadian airport had the same average visibility as the far northern stations, then $I_{reg} = 0.5$ for that region. Results of the computation are shown in Fig. A6.

A national index of regional air quality was computed by weighting each value of I_{reg} according to the metropolitan population of the city near which the airport lay. This method is the same as was used in Table II. The national index was computed for 96 urban areas comprising a combined metropolitan population of 10,800,000.

indication of the quality of this standard, only two cities out of the 31 for which the Environmental Protection Service collects specific pollutant data (Medicine Hat and Lethbridge) had a higher average visibility for 1971 than the average of Whitehorse and Yellowknife.

Since the average visibility at airports was a function of the overall average of air pollutants in the vicinity, the index of visibility had to be approximately numerically comparable to the index I_{sp} derived from the specific pollutant data, described in the last section. It was found after computation that this goal could be accomplished by dividing the visibility index by a factor 2.

The index of inter-urban air quality then became

(A13)

$$I_{reg} = \frac{V_{tn}}{2V_{sp}}$$

where I_{reg} is the index of inter-urban (or regional) air quality, V_{tn} is the average visibility for the two far northern stations, and V_{sp} is the average visibility for 1971 for each airport. It was found that $V_{tn} = 14.6$ (in miles). If a Canadian airport had the same average visibility as the far northern stations, then $I_{reg} = 0.5$ for that region. Results of the computation are shown in Fig. A5.

A national index of regional air quality was computed by weighting each value of I_{reg} according to the metropolitan population of the city near which the airport lay. This method is the same as was used in Table 11. The national index was computed for 96 urban areas comprising a combined metropolitan population of 10,800,000.

The national index of inter-urban air quality was 0.587.

III Index of Industrial Emissions

As a third and final component of an air quality index, the index of industrial emissions I_{ie} was computed. This index was designed to give a measure of air quality outside the urban areas in Canada, and as a guide to the relative potential for air pollution effects on vegetation, soil, water and wildlife, rather than on human health as is the case with the index of specific pollutants.

The index I_{sp} was found by using actual physical measurements of air quality in urban areas. However, these measurements are generally not available for non-urban areas. Since the level of air pollution in these latter areas is important in evaluating air quality for all of Canada, use was made of the "Nationwide Inventory of Air Pollutant Emissions", supplied by the Environmental Protection Service. These listed the estimated weight of emissions for major point and area sources, defined as those emitting more than 5000 tons of a particular pollutant a year. These estimates are based on level of production of various commodities, the level of emission controls installed, and other factors.

Although emission estimates have been made for more than two pollutants, use was made only of two, dealing with sulphur dioxide and suspended particulate matter. These two were chosen because these pollutants fell into the first group of pollutants mentioned in section I, i.e., those for which extensive physical measurements have been made.

The national index of inter-urban air quality was 0.587.

III Index of Industrial Emissions

As a third and final component of an air quality index, the index of industrial emissions I_{18} was computed. This index was designed to give a measure of air quality outside the urban areas in Canada, and as a guide to the relative potential for air pollution effects on vegetation, soil, water and wildlife, rather than on human health as is the case with the index of specific pollutants.

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Although emission estimates have been made for more than two pollutants, use was made only of two, dealing with sulphur dioxide and suspended particulate matter. These two were chosen because these pollutants fell into the first group of pollutants mentioned in section I, i.e., those for which extensive physical measurements have been made.

The data on emissions could be grouped into two sections. The first was those locations where physical measurements of air quality have been made; these were termed "urban". All other locations were termed "industrial", although it is realized that a small proportion of the emissions in those areas were non-industrial in origin. The index of industrial emissions then was

$$I_{ie} = \frac{E_{ip}}{P_{prov}} \bigg/ \frac{E_{ic}}{P_{can}} \quad (A14)$$

where E_{ip} is the sum of the industrial emissions for a given pollutant (either sulphur dioxide or suspended particulate matter) for a province, and P_{prov} is the population of that province. E_{ic} is the sum of the industrial emissions for a given pollutant for all of Canada, and P_{can} is the population of Canada. In this way, we can take account of the relative contributions of each of the provinces, both compared to each other and to the Canadian average.

There were a small number of cities, including Sudbury, Sault Ste. Marie, Sarnia, Thunder Bay (all in Ontario) and Sydney, Nova Scotia, for which physical measurements of air quality have been taken, but were judged as industrial for purposes of this sub-index. This judgement introduced a certain degree of double-counting in the index of specific pollutants I_{sp} , but changes this latter index by well under one percent. The reason why this change is small is that the indices I_{sp} for each city are weighted according to population (see Table II), and the cities referred to in this paragraph have comparatively small populations compared

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to the large Canadian metropolises.

For the sulphur dioxide index, 31 industrial sources in 9 provinces were noted. The total emissions for all Canada, or E_{ip} , was 6,222,000 tons, of which 5,363,000 tons were emitted from industrial sites. The provincial averages are shown in Fig. A7.

To compute a national index for industrial emissions of sulphur dioxide, the provincial averages were weighted according to the scheme of Table II. However, in this case the weights used were the populations of the provinces rather than those of the municipalities. The national index of sulphur dioxide industrial emissions computed in this way was 0.87.

A similar method was used to compute the suspended particulate matter industrial emissions index. Equation (A14) was used, with the emissions E_{ip} and E_{ic} referring to suspended particulate matter. Again, some municipalities were doubled-counted with respect to the index I_{PM} (see section I), but this affected the results of this latter index only slightly.

For the suspended particulate matter index, 28 industrial sources in 9 provinces were noted. The total emissions for all Canada, or E_{ip} , was 758,000 tons, of which 566,000 tons were emitted from industrial sites. The provincial averages are shown in Fig. A8.

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For the suspended particulate matter index, 28 industrial sources in 9 provinces were noted. The total emissions for all Canada, or E_{ip} , was 758,000 tons, of which 266,000 tons were emitted from industrial sites. The provincial averages are shown in Fig. A8.

To compute a national index for industrial emissions of suspended particulate matter, the provincial averages were weighted according to the scheme of Table II. Again, the weights used were

the populations of the provinces rather than those of the municipalities. The national index of suspended particulate matter from industrial emissions was then 0.75.

When sufficient physical measurements of air quality are available for other specific pollutants, the total national index for industrial emissions will be

$$I_{ie} = \sqrt{\frac{(I_{ieSPM})^2 + (I_{ieSO_2})^2 + (I_{ieCO})^2 + (I_{ieNO_x})^2 + (I_{ieHC})^2}{5}} \quad (A15)$$

where the denominator of the right-hand side is the sum of the weights, and each component of the industrial emissions index is weighted equally. The five components refer to suspended particulate matter, sulphur dioxide, carbon monoxide, oxides of nitrogen, and hydrocarbons, respectively. Because extensive physical measurements are not now available for these last three pollutants, the equation used in this present index for the industrial emissions is

$$I_{ie} = \sqrt{\frac{(I_{ieSPM})^2 + (I_{ieSO_2})^2}{2}} \quad (A16)$$

Using the values for the two components noted above, $I_{ie} = 0.81$.

IV Combined Air Quality Index

The three components of the combined air quality index, dealing with specific pollutants, regional air quality, and industrial emissions, were combined by the root-mean-square technique with weights assigned of 5,3, and 2, respectively. These weights

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$$(A7B) \quad I_{ie} = \sqrt{\frac{I_{ieSPM}^2 + I_{ieSO_2}^2}{2}}$$

Using the values for the two components noted above, $I_{ie} = 0.87$.

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INTERPRETATION

were designed to reflect the approximate contributions of each index to the overall Canadian air quality index. Thus the overall air quality index is

$$I_{air} = \sqrt{\frac{5 (I_{sp})^2 + 3 (I_{reg})^2 + 2 (I_{ie})^2}{10}} \quad (A17)$$

where the denominator is the sum of the weights. Using equation (A17), we have $I_{air} = 0.99$.

In Fig. A1, we see the index of suspended particulate matter, I_{sp} . The highest regions are in Southern Ontario, with high regions also in Quebec, Alberta and British Columbia. Levels of I_{sp} in the Maritimes and most of the Prairies tend to be low. The national average of I_{sp} was 1.33 and is not relatively high.

In Fig. A2, the index of sulphur dioxide, I_{SO_2} , is shown.

We see that most of the cities in Eastern Canada had relatively high values of the index, as compared to those in Western Canada. The prime exceptions were London and Ottawa, which are relatively unindustrialized. Note that the scale of this index is somewhat larger than others in this chapter, because of the larger range of the index. This means, for example, that a city which would have been coloured pink in another map would here be coloured yellow. The national average for I_{SO_2} was 1.61, which made it even higher than the index for suspended particulate matter.

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INTERPRETATION

Because of the differences in the types of data available, some of the maps in this chapter differ in appearance from others. However, all show some aspect of air quality as clearly as possible. Where sufficient data were available, a map was "contoured". The basis and assumptions of this method are discussed in the Methodology.

The first of the three sub-indices we consider is the Index of Specific Pollutants. In Fig. A1, we see the index of suspended particulate matter, I_{SPM} . The highest regions are in Southern Ontario, with high regions also in Quebec, Alberta and British Columbia. Levels of I_{SPM} in the Maritimes and most of the Prairies tend to be low. The national average of I_{SPM} was 1.33 and so was relatively high.

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I_{COH} . As mentioned in the methodology, it is difficult to compare the values of the index from city to city. The national average for I_{COH} was 1.11.

This concludes the discussion on the three specific pollutants for which data was relatively abundant. The next three sub-indices had somewhat less data.

In Table A4, the index of carbon monoxide, I_{CO} , is shown. We see that most of the values of the index are fairly low. This is borne out by the national average of 0.41, which was the lowest of all the specific pollutants considered.

In Table A5, the total oxidants index, I_{OX} , is shown. The national average, 1.69, was the highest of the 6 specific pollutants considered, and this is borne out in the values shown in this table.

In Table A6, the index for oxides of nitrogen, I_{NO_x} , is shown. The national average was 0.63, putting it on the low side compared to other air pollutants. We see a very wide variation in the values for this index.

The way the indices of specific pollutants varied with time was also of interest. Graphs were constructed for the indices of suspended particulate matter, sulphur dioxide, and coefficient of haze.

Fig. A3 shows the change in I_{SPM} , the index for suspended particulate matter, with time. In contrast to the two following graphs we see comparatively little change from month to month.

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The largest values are in April and May, at around 1.6. This may be due in part to natural conditions of spring air dust.

In Fig. A4, sulphur dioxide is shown. We see very large changes in this index with changes in season. The index is very high (around 3.0) in the first two months of the year, but decreases quickly to a minimum of around 1 in July and August. This change is of course due to the fact that the bulk of industrial and home-heating uses of sulphur containing fuels occur in the winter months.

Fig. A5 shows the change in I_{COH} , coefficient of haze, with time. The graph is similar to that for sulfur dioxide, except that the values are not as high. The index has a maximum of around 1.3 to 1.5 in the fall and winter months from October to March, and then declines to about 0.75 in the summer months. Again, this is apparently due to heating effects in the winter months.

The index of inter-urban air quality, based on visibility at airports, is shown in Fig. A6. Because of the large amount of data available, the indices were "contoured" by the methods discussed in the Methodology. Regions of highest value (greater than about 0.6) are in southwestern Ontario. The indices in that region tend to be at least 20% higher than in most other areas of Canada. However, the entire region from Windsor to about Quebec City tends to have higher indices than Western Canada. The region of high indices also extends into the Maritimes, with the southern

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Maritimes tending to have higher indices than the north.

In Western Canada, there is a ridge of extremely low indices with values less than 0.5 (very high visibilities), running along the southern extremes of British Columbia, Alberta and Saskatchewan. The index rises as one proceeds farther north, but it still remains low and comparable to the average for the Far Northern stations. In British Columbia, Vancouver has an index comparable to that of an average Eastern station, but considerably less than southern Ontario.

The third component of the air quality index was the index of industrial emissions. Because of the way data were supplied, it was decided to show the values of the two sub-indices in this component on a provincial basis. In Fig. A7, we see the index for industrial emissions of sulphur dioxide. The Prairie Provinces and Ontario have relatively high values of the index. The Maritime Provinces have relatively low values, and other provinces fall in between. The values of the indices are governed to a large extent by the degree of concentration of industries outside major cities in Canada, as well as the relative proportions of total Canadian population in each province.

Fig. A8 shows the index for industrial emissions of suspended particulate matter. This map is different from Fig. A7 because the emissions from different industries vary considerably. Newfoundland, Nova Scotia, Alberta and Saskatchewan now have the highest values of this index. Manitoba and Prince Edward Island

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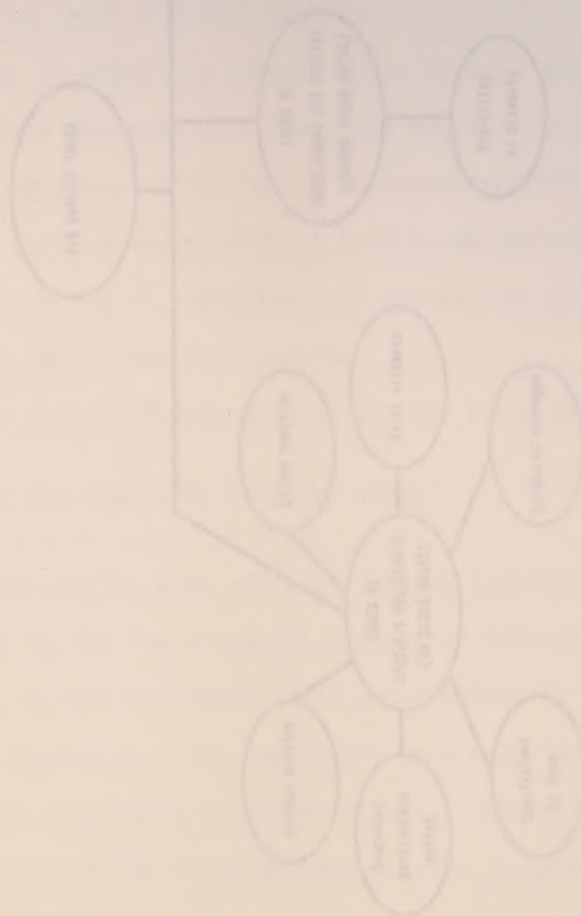
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have the lowest values, and the other provinces fall in between.

Because of the relatively small amount of data available for many areas, it was not possible to compile an overall air quality index for specific cities and provinces. However, this may be done in the future. Combining the three components of the air quality index by the way discussed in the Methodology, the overall air quality index had a value of 0.99.



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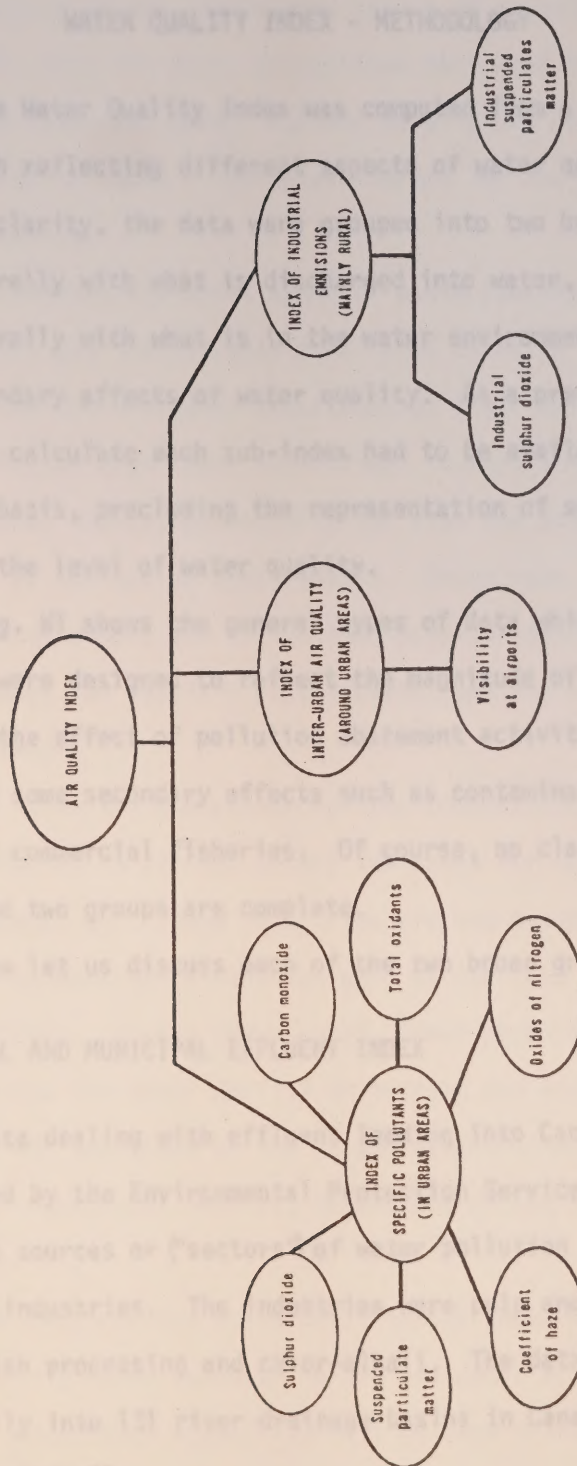
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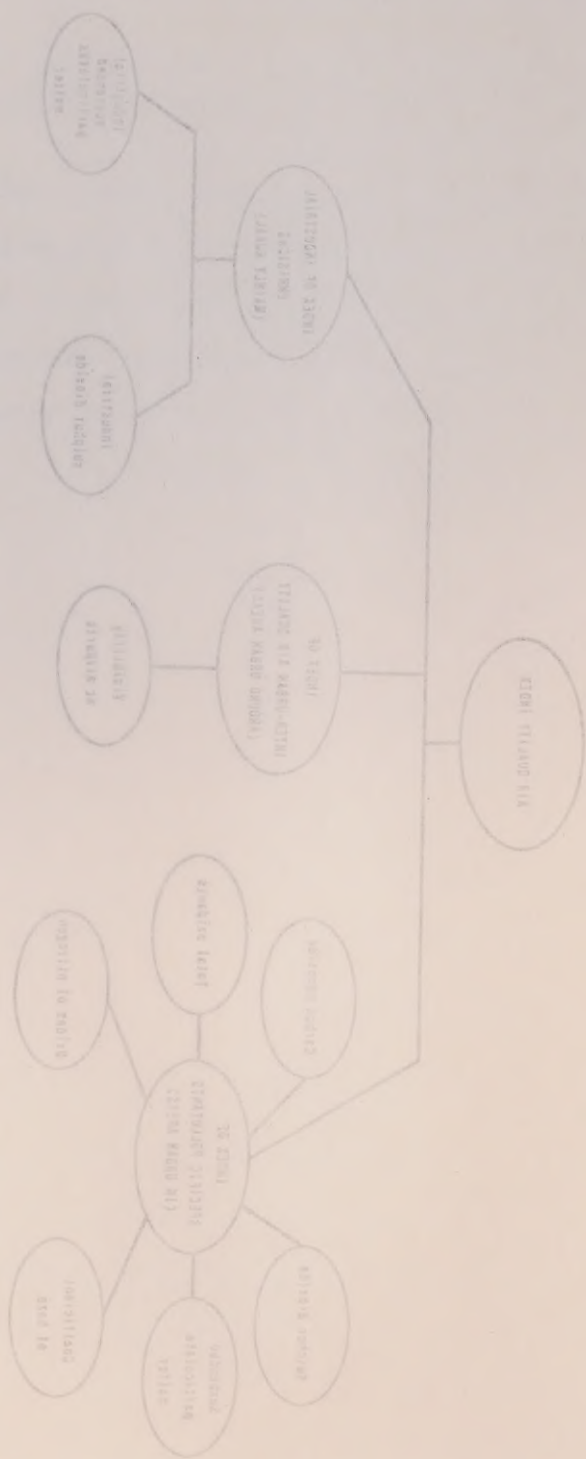
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WATER QUALITY INDEX - METHODOLOGY

The Water Quality Index was computed from a series of sub-indices, each reflecting different aspects of water quality. For purposes of clarity, the data were grouped into two broad areas: one dealing generally with what is discharged into water, and the other dealing generally with what is in the water environment, as well as certain secondary effects of water quality. As a prerequisite, the data used to calculate each sub-index had to be available on a nation-wide basis, precluding the representation of some factors influencing the level of water quality.

Fig. W1 shows the general types of data which were included. Sub-indices were designed to reflect the magnitude of polluted effluent discharges, the effect of pollution abatement activities, natural water quality, and some secondary effects such as contamination of water supplies and commercial fisheries. Of course, no claim is made that either of the two groups are complete.

Now let us discuss each of the two broad groupings.

I INDUSTRIAL AND MUNICIPAL EFFLUENT INDEX

Data dealing with effluent loading into Canadian waterways were supplied by the Environmental Protection Service. These data dealt with 5 sources or ("sectors") of water pollution - municipalities and 4 major industries. The industries were pulp and paper, petroleum refining, fish processing and chlor-alkali. The data were broken down geographically into 131 river drainage basins in Canada and also combined provincially.

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Because of the complicated nature of devising this effluent loading index, only the major assumptions that went into its construction are discussed here. Further details are contained in a report prepared by James F. MacLaren Limited for the Environmental Protection Service.

To include different types of waste constituents in one combined index, the constituents were rated relative to one another on the basis of the estimated importance of their effect on water use. Three major "water uses" were identified: suitability for potable (drinking) water supply, suitability for fish and aquatic life, and suitability for recreation (aesthetics). Other uses, such as industrial water supply and irrigation, usually involve less stringent criteria, except for specific constituents, and are not important in every river basin.

In Table W1, objectives for the concentration of various waste constituents in ambient waters are shown for each of the three major use categories. These objectives are the maximum permissible or allowable concentration at which each of the uses is not detrimentally affected. Except where noted, these objectives are taken from "Guidelines for Water Quality Objectives and Standards" Technical Bulletin No. 67, published by the Inland Waters Directorate, Environmental Management Service, Department of the Environment, Ottawa, 1972.

The choice of the waste constituents shown was on the basis of what is currently being measured in the effluents of a variety of industries. Additional objectives will be used if other constituents are measured in the future, or when objectives not yet established, are available.

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In Table VI, objectives for the construction of various water constituents in ambient waters are shown for each of the three major categories. These objectives are the maximum permissible concentration at which each of the uses is not unduly and adversely affected. These limits noted have objectives which are based on the best available scientific data and standards. Technical Committee No. 25, established by the United States Department of Environment and Natural Resources, Department of the Environment, advised the following:

The objective for water constituents shown was on the basis of the best available data and the objectives of a variety of uses. The objectives will be used as a guide in the future, but they are not intended to be used as a standard for future evaluation.

MAXIMUM ALLOWABLE WATER USE OBJECTIVES

Waste Constituent	← Milligrams per Litre of water →				Weighting Factor
	Potable (Drinking) Water	Fish and Aquatic Life	Aesthetics & Recreation	Most Sensitive Objective	
Dissolved Oxygen Deficit (Biochemical Oxygen Demand)	-	3	-	3	0.33
Suspended Solids	-	25	-	25	0.04
Ammonia	0.5	1*	-	0.5	2
Cadmium	0.01	0.01*	0.01	0.01	100
Chromium	0.05	0.5*	0.05	0.05	20
Copper	1.0	0.03*	-	0.03	33.3
Iron	0.3	0.3*	-	0.3	3.33
Lead	0.05	0.05*	0.05	0.05	20
Phosphorus	-	*0.015**	-	0.015	66.7
Phenols	0.001	-	-	0.001	1000
Cyanide	0.2	-	-	0.2	5
Mercury	0.005***	-	-	0.005	200

* Water Quality Criteria, Report of National Technical Advisory Committee, Federal Water Pollution Control Administration, Washington, D.C., April 1968.

** Symposium on stream flow regulation, U.S. Dept. of Health, Education & Welfare, June 1965.

*** U.S. Public Health Service, Mercury in water supplies, J. American Water Works Association, vol. 62, no. 5, p. 285, May 1970.

It should be noted that the objective shown for phosphorus, under fish and aquatic life, is the "best available number", based on concentration. It is recognized, however, that the risk of lake eutrophication - detrimental to fish, aquatic life and recreation - is dependent more on the depth of a lake and loading of nutrients rather than on the concentration.

We recognize that the toxicity of metals increases in soft waters due to synergistic effects. The objectives for the toxicity of substances to fish and aquatic life, shown in Table W1, are general objectives used in the United States. Bulletin 67 shows that in some soft waters, these objectives are not stringent enough. The U.S. objectives were used for the present, however, to retain a consistent set of objectives for toxic substances.

The most sensitive objectives were identified and are defined as the most sensitive concentration of a particular waste constituent, at which any of the three main uses of water could be impaired. This is shown in Table W1, column 4. Finally, the numbers in the 5th column represent the relative weighting of the waste constituents. These weighting factors are the reciprocals of the most sensitive objective in column 4. The lower the objective, the higher the relative weighting. This means that the more potentially hazardous the substance in a given amount of water the greater the relative weight it is given.

As an example, consider 1 mg of cadmium and 1 mg ammonia being discharged into a body of water. It takes 2 litres of water to dilute 1 mg ammonia to a level where the most sensitive objective of 0.5 mg per litre is met, and 100 litres of water to dilute 1 mg

It should be noted that the objective shown for phosphorus, under fish and aquatic life, is the "best available number", based on concentration. It is recognized, however, that the risk of lake eutrophication - detrimental to fish, aquatic life and recreation - is dependent more on the depth of a lake and loading of nutrients rather than on the concentration.

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As an example, consider 1 mg of cadmium and 1 mg ammonia being discharged into a body of water. It takes 2 litres of water to dilute 1 mg ammonia to a level where the most sensitive objective of 0.2 mg per litre is met, and 100 litres of water to dilute 1 mg

cadmium to its most sensitive objective of 0.01 mg per litre. In other words, cadmium is 100:2 or 50 times more objectionable on an equal weight basis than ammonia. The weighting factors in Table W1 are therefore relative weights computed on an equal weight basis, for each constituent.

In the case of biological oxygen demand (BOD), 1 mg BOD represents the amount of organic material requiring 1 mg of oxygen for decomposition. If 1 mg BOD is added to 1 litre of water it will therefore cause an oxygen deficit of 1 mg per litre. The maximum allowable oxygen deficit, for fish and aquatic life, at an average summer receiving water temperature of 21°C at sea level is 3 mg per litre (figure VII 2, page 106, Bulletin 67). The BOD weight factor of 0.33 in column 5 of Table W1 therefore means that it takes 0.33 litres of water to dilute 1 mg BOD, thus resulting in an oxygen deficit of 3 mg per litre.

Further information on the effect of various substances on receiving waters and objectives for various uses can be obtained from Bulletin 67 published by the Environmental Management Service.

Using the weighting factors given in column 5, Table W1, the equivalent effluent load from an industrial or municipal sector is then:

$$E_L = W_1 P_1 + W_2 P_2 + W_3 P_3 + \dots \quad (W1)$$

where W_1 is the weighting factor for the first constituent, and P_1 is the actual weight discharged of the first constituent per year.

Similarly, the subscripts "2" refer to the 2nd constituent and so on.

In this way we take account of all the constituents in Table W1 for

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Further information on the effect of various substances on receiving waters and objectives for various uses can be obtained from Bulletin 67 published by the Environmental Management Service. Using the weighting factors given in column 5, Table W1, the equivalent effluent load from an industrial or municipal sector is then:

$$E_x = W_1 P_1 + W_2 P_2 + W_3 P_3 + \dots \quad (W1)$$

where W_1 is the weighting factor for the first constituent, and P_1 is the actual weight discharged of the first constituent per year. Similarly, the subscript "2" refers to the 2nd constituent and so on. In this way we take account of all the constituents in Table W1 for

each sector. As long as the weights W_1 , W_2 etc., are used relative to each other, they may be considered dimensionless. As a result, for convenience we will use these weights without dimensions in the following equations.

It should be noted here that some constituents of waste discharges such as bacteria, degree of acidity, thermal discharge or turbidity are not included in Table W1 or in the following effluent loading index. These constituents or properties could not be expressed on a weight per unit volume basis (that is, mg per litre etc.), and therefore could not be treated by the method described here at this time. Consideration of these parameters will be included in subsequent editions.

For this initial effluent loading index, the waste constituents considered for each sector were: (1) municipalities - BOD, suspended solids and phosphorus; (2) pulp and paper - BOD and suspended solids; (3) fish processing - BOD and suspended solids; (4) petroleum refining - BOD, suspended solids, phenols, cyanides and ammonia (5) chlor-alkali - mercury.

Before discussing in detail each of these sectors, let us mention how the indices for effluent loadings were developed. Because of the nature of the available data, the formulation differs somewhat from other indices in this publication. The effluent loads as computed by equation (W1) are in pounds (per year).

Because quantities of wastes discharged will undoubtedly be higher in those urban areas where industrial activity is the greatest, we felt that two indexes were necessary to describe in an accurate

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Because quantities of wastes discharged will undoubtedly be higher in those urban areas where industrial activity is the greatest, we felt that two indexes were necessary to describe in an accurate

manner this important environmental input component. We needed to devise a term which quantified the efforts of different sectors to abate pollution, and this was achieved by the following equation:

$$E_{ul} = \frac{E_l}{X_l} \quad (W2)$$

where E_{ul} is the unit load for a particular sector, E_l is defined in equation (W1), and X_l is the weight of product manufactured, in the case of the industrial sectors, or the population served by municipal water systems, in the case of the municipal sector. Of course, E_{ul} will be unitless for the 4 industrial sectors, and will have the units of pounds per year per person for the municipal sector.

Because of the different bases used in computing the unit loads for the 5 sectors, it was found convenient, for graphical purposes, to show a "normalized unit load index", defined as follows:

$$I_{nul} = \frac{E_{ul}}{E_{ul_{av}}} \quad (W3)$$

Here E_{ul} is defined by equation (W2), and $E_{ul_{av}}$ is the average Canadian unit load for a particular sector. In this way, we can show index variations, both provincially and on a drainage basin basis, without problems created by the fact that E_{ul} varies considerably from sector to sector.

The normalized unit load index is shown in Figs. W2, W4, W6, and W9. Essentially, it is an attempt to show the relative levels of pollution abatement for various sectors across Canada. In some cases, where data for years previous to the latest one were available, $E_{ul_{av}}$

manner this important environmental input component. We needed to devise a term which quantified the efforts of different sectors to abate pollution, and this was achieved by the following equation:

$$(W2) \quad E_{u2} = \frac{E_{u2}}{X_2}$$

where E_{u2} is the unit load for a particular sector, E_u is defined in equation (W1), and X_2 is the weight of product manufactured, in the case of the industrial sectors, or the population served by municipal water systems, in the case of the municipal sector. Of course, E_u will be unitless for the industrial sectors, and will have the units of pounds per year per person for the municipal sector.

Because of the different bases used in computing the unit loads for the 2 sectors, it was found convenient, for graphical purposes, to show a "normalized unit load index", defined as follows:

$$(W3) \quad E_{u2}^* = \frac{E_{u2}}{E_{u2}^{av}}$$

Here E_{u2}^* is defined by equation (W3), and E_{u2}^{av} is the average Canadian

unit load for a particular sector. In this way, we can show index variations, both provincially and on a drainage basin basis, without problems created by the fact that E_{u2} varies considerably from sector to sector.

The normalized unit load index is shown in Figs. W2, W4, W6, and W8. Essentially, it is an attempt to show the relative levels of pollution abatement for various sectors across Canada. In some cases, where data for years previous to the latest one were available, E_{u2}^{av}

was taken for the earliest year (base year). For example, the unit loads E_{ul} for the chlor-alkali industry for 1972 ranged from 0.21 to 0.58, on a regional basis. The average unit load for 1969 for all of Canada was 27.8. Thus the normalized unit load index for 1972 ranged from $\frac{0.21}{27.8} = 0.0076$ to $\frac{0.58}{27.8} = 0.021$. The base years used in calculation of the normalized unit load index are discussed in the sections devoted to particular sectors.

As well as the normalized unit index, we need an index which will convey the idea of the actual equivalent loads being discharged to the water environment. This is achieved by utilizing a total load index:

$$I_l = \frac{E_l}{E_{l_t}} \quad (W4)$$

where E_l is defined by equation (W1), and represents the equivalent load for a designated province or region, and E_{l_t} is the total equivalent load for all of Canada, for a particular sector. This total load index reflects the total waste discharged to the environment by this sector. As an example, the municipal total load index will tend to be high in those provinces and river drainage basins which have high populations, if the degree of treatment of wastes were the same across Canada. Because it is not, the total load index does not have an exact correlation with population, or number of plants of a particular industry. The total load indices for the various sectors are shown in Figs. W2, W5, W7, W8 and W10. In effect, the indices represent the fraction of the total Canadian discharge of wastes contributed by a given sector in a given province or region. These indices were calculated only for the latest year for which data were available.

was taken for the earliest year (base year). For example, the unit loads E_u for the chlor-alkali industry for 1975 ranged from 0.27 to 0.58, on a regional basis. The average unit load for 1969 for all of Canada was 27.8. Thus the normalized unit load index for 1975 ranged from $\frac{0.27}{27.8} = 0.0076$ to $\frac{0.58}{27.8} = 0.021$. The base years used in calculation of the normalized unit load index are discussed in the sections devoted to particular sectors.

As well as the normalized unit index, we need an index which will convey the idea of the actual equivalent loads being discharged to the water environment. This is achieved by utilizing a total load index:

$$I_t = \frac{E_t}{E_{t,c}}$$

where E_t is defined by equation (W1), and represents the equivalent load for a designated province or region, and $E_{t,c}$ is the total equivalent load for all of Canada, for a particular sector. This total load index reflects the total waste discharged to the environment by this sector. As an example, the municipal total load index will tend to be high in those provinces and river drainage basins which have high populations, if the degree of treatment of wastes were the same across Canada. Because it is not, the total load index does not have an exact correlation with population, or number of plants of a particular industry. The total load indices for the various sectors are shown in Figs. W2, W3, W4 and W10. In effect, the indices represent the fraction of the total Canadian discharge of wastes contributed by a given sector in a given province or region. These indices were calculated only for the latest year for which data were available.

Because of the limited nature of our knowledge about the ecological impact of effluent constituents, we are aware that the consideration and inclusion of new sources of data in future years could bias the index unduly. These sources could be (i) a new waste constituent or one which was not considered important previously, (ii) the change of weighting factors in light of new information, or (iii) the addition of a new industrial sector for which there was no previous data available.

To solve the problems created by (i) and (ii), the normalized unit load index and total load index would have to be re-computed for previous years, with the inclusion of the new source of information, and based on the best available estimate as to its contribution in previous years. This would eliminate any bias.

Source (iii) introduces bias only in the overall effluent loading index (to be discussed next), and so does not change I_{nul} and I_l for other sectors. In this case, the overall loading index would have to be recomputed on the basis of the best available estimates of the contribution of the new sectors in previous years. Sample recalculations of typical cases of (i), (ii), and (iii) are available but have not been included here for reasons of brevity.

In order to compute an overall effluent loading index taking into account all 5 sectors, the following equation was used:

$$I_{lt} = \frac{E_{l1} + E_{l2} + E_{l3} + \dots}{E_{l1B} + E_{l2B} + E_{l3B} + \dots} \quad (W5)$$

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Source (iii) introduces bias only in the overall effluent loading index (to be discussed next), and so does not change I_{LUS} and I_L for other sectors. In this case, the overall loading index would have to be recomputed on the basis of the best available estimates of the contribution of the new sector in previous years. Sample recalculations of typical cases of (i), (ii), and (iii) are available but have not been included here for reasons of brevity. In order to compute an overall effluent loading index taking into account all 5 sectors, the following equation was used:

(WS)

$$I_{LUS} = \frac{E_{L1} + E_{L2} + E_{L3} + \dots}{E_{L1B} + E_{L2B} + E_{L3B} + \dots}$$

where I_{lt} is the overall effluent loading index, E_{l1} is the equivalent effluent load for the first sector for the latest year, E_{l1B} is this load for the base year, and so on. When data from previous years were not available, the base year was the latest year. If, in the following sections, the years used are not mentioned, both the base and latest year were 1971.

Table W2 shows the actual equivalent effluent loads used in calculating I_{lt} by means of equation (W5).

TABLE W2

Sector	Base Year Equivalent Effluent Load (Millions of pounds/year)	Present Year Equivalent Effluent Load (Millions of pounds/year)
Municipal	3179	3179
Pulp and Paper	1095	1057
Petroleum and Refining	1420	1420
Fish Processing	47.4	47.4
Chlor-Alkali	15.7	0.24

Calculation shows that the value of I_{lt} is

$$I_{lt} = \frac{5704 \text{ million pounds/year}}{5758 \text{ million pounds/year}}$$

$$= 0.99$$

Now we shall discuss the specific assumptions made for each sector. The types of waste constituents considered for each sector have already been mentioned. In all cases, the latest year used was 1971 unless otherwise mentioned.

where I_{LF} is the overall effluent loading index, E_{LF} is the equivalent

effluent load for the first sector for the latest year, E_{LF} is this

load for the base year, and so on. When data from previous years were

not available, the base year was the latest year. If, in the following

sections, the years used are not mentioned, both the base and latest

year were 1971.

Table WS shows the actual equivalent effluent loads used in

calculating I_{LF} by means of equation (WS).

TABLE WS

Sector	Base Year Equivalent Effluent Load (Millions of pounds/year)	Present Year Equivalent Effluent Load (Millions of pounds/year)
Municipal	3179	3179
Pulp and Paper	1092	1092
Petroleum and Refining	1420	1420
Fish Processing	47.4	47.4
Chlor-Alkali	12.7	0.24

Calculation shows that the value of I_{LF} is

$$I_{\text{LF}} = \frac{5708 \text{ million pounds/year}}{5788 \text{ million pounds/year}}$$

$$= 0.99$$

Now we shall discuss the specific assumptions made for each

sector. The types of waste constituents considered for each sector

have already been mentioned. In all cases, the latest year used was

1971 unless otherwise mentioned.

(i) Municipal Sector

Only that fraction of the waste load attributable to the public sector was considered. In other words, the load contribution to municipal systems by the industrial sector was not included.

Since the actual level of waste contributions by many municipalities is not known, calculations were made by assuming that there is a per capita contribution of the three waste constituents considered for this sector. It was assumed that the per capita contributions were: BOD-0.17 pounds per day; suspended solids - 0.20 pounds per day, and phosphorous - 3.7 pounds per year.

It should also be noted that only those municipalities for which data on sewage treatment facilities were available were considered. This meant that a total population of 13,900,000 was used in the calculations.

In determining the actual loading of the three waste constituents from municipal sewage treatment facilities, assumptions had to be made regarding the efficiency of the treatment facilities. These assumptions are listed below, in Table W3. The data given in Table W3 represents theoretical values. We recognize that a large number of such installations fall short of these efficiencies. However, it was felt that this approach would provide a reasonable estimate.

TABLE W3

Waste Characteristics	Primary Treatment	Lagoon Treatment	Primary Plus Secondary Treatment	Septic Tank Treatment
BOD	30	90	90	100
Suspended Solids	60	95	95	100
Phosphorus	10	10	30	100

(f) Municipal Sector

Only that fraction of the waste load attributable to the public sector was considered. In other words, the load contribution to municipal systems by the industrial sector was not included. Since the actual level of waste contributions by many municipalities is not known, calculations were made by assuming that there is a per capita contribution of the three waste constituents considered for this sector. It was assumed that the per capita contributions were: 800-0.17 pounds per day; suspended solids - 0.20 pounds per day, and phosphorus - 3.7 pounds per year. It should also be noted that only those municipalities for which data on sewage treatment facilities were available were considered. This meant that a total population of 13,900,000 was used in the calculations.

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BOD	30	90	90	100
Suspended Solids	60	95	95	100
Phosphorus	10	10	30	100

As an example of the use of this table, consider a municipality of population 20,000, which uses a well-operated lagoon to treat its sewage. The untreated (influent) BOD would be estimated to be $0.17 \frac{\text{lb}}{\text{day}}$ $\times 20,000 = 3400 \frac{\text{lb}}{\text{day}}$. Since the efficiency of the lagoon treatment process is assumed to be 90%, the calculated effluent BOD loading is $3400 \frac{\text{lb}}{\text{day}} \times 0.10 = 340 \frac{\text{lb}}{\text{day}}$. The factor 0.10 corresponds to 10%, or 100% - 90%, the latter figure being the efficiency. Since the weighting factor for BOD is 0.33, (from Table W1), the "equivalent load" is $340 \times 0.33 = 113 \frac{\text{lb}}{\text{day}}$.

In a similar manner, the untreated suspended solids would be $0.20 \times 20,000 = 4000 \frac{\text{lb}}{\text{day}}$. The effluent would then contain $4000 \times 0.05 = 200 \frac{\text{lb}}{\text{day}}$. The equivalent load is then $200 \times 0.04 = 8 \frac{\text{lb}}{\text{day}}$, making a total equivalent load for BOD and suspended solids of $113 + 8 = 121 \frac{\text{lb}}{\text{day}}$. The phosphorus equivalent load is calculated in a similar fashion.

(ii) Petroleum Refining Industry

For this industry, information was available on the actual discharge loading of five pollutants (listed before equation (W2)), and therefore further assumptions were not required.

(iii) Pulp and Paper Industry

Information was available only on BOD and suspended solids. Since some of the plants discharge to municipal sewer systems, assumptions had to be made regarding the efficiency of these systems

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$$3400 \text{ lb/day} \times 0.10 = 340 \text{ lb/day} \quad \text{The factor 0.10 corresponds to 10%, or}$$

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factor for BOD is 0.33 (from Table VI), the "equivalent load" is

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$$0.50 \times 20,000 = 10,000 \text{ lb/day} \quad \text{The effluent would then contain } 10,000 \times 0.05 =$$

$$500 \text{ lb/day} \quad \text{The equivalent load is then } 500 \times 0.04 = 20 \text{ lb/day, making a total}$$

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Information was available only on BOD and suspended solids.

Since some of the plants discharge to municipal sewer systems,

assumptions had to be made regarding the efficiency of these systems

in removing the load discharged by these plants. In general, most municipalities receiving pulp and paper mill wastes have both primary and secondary facilities. It was assumed that the average treatment efficiencies for the facilities receiving pulp and paper waste waters were 70% for BOD and 70% for suspended solids. The base year for the calculation of the overall effluent loading index I_{et} of equation (W5) was 1970.

(iv) Fish Processing Industry

The effluent loadings from fish processing plants were generated using loading factors which have been established for plants processing different types of fish. These factors are on file in the Department. In general, a normal operating period of 100 days was assumed, with the exception of plants in British Columbia where a 120 day operating period was assumed.

(v) Chlor-Alkali Industry

In the chlor-alkali industry, information was available only on mercury, for the period prior to and after the disclosures of mercury loading in 1969 and 1970. The information for 1969 was used as a base year for calculating all of these sub-indices. The latest (or present) year was 1972.

In concluding this section on the methodology of calculating effluent loadings, some mention must be made of the method of graphical presentation. Basin-by-basin maps are available for all of the 5 sectors, except the chlor-alkali industry. In general, they were combined into provincial maps in the interests of simplicity and of conservation of space.

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If upon subsequent review, it is decided that these additional maps are essential to the publication, they will be included in future editions.

In any case, however, Fig. W10 shows, on a basin-by-basin basis, the combined total load index for all of the 5 sectors, thus giving an overall total contamination picture in a detailed way.

II Ambient Water Quality Index

This index relates to what is in the water environment (water, sediment, ground water, etc.), rather than what is discharged into the water, which is dealt with in the previous broad section on effluents. The latter index discussed wastes from municipalities and from industries; the present index deals with trace metal contamination of water supplies, the suitability of rivers in terms of turbidity for drinking water supplies and contact recreation, and the mercury contamination of fish landed commercially. It should be noted that the first and third of these are secondary rather than primary aspects of water quality.

We shall now deal with these in order.

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We shall now deal with these in order.

Trace Metals in Municipal Water Supplies

The Environmental Management Service of Environment Canada has collected data on the concentration of trace metals in municipal water supplies for 293 municipalities with an aggregate population of over 4,300,000. The water supplies were analysed for lithium, copper, zinc, chromium, cadmium, and for total water hardness expressed as calcium carbonate. As a general rule, 6 samples were tested for each metal. They were taken at two points in the water distribution network for at least two dates in 1970-71. The data are few, and because samples were not preserved before analysis, the results can be considered only as an estimate of trace metal levels in water supplies. However, for purposes of national trend evaluation, the data are considered satisfactory. The data were divided up into three parts: (a) cadmium and chromium (chemicals which should ideally not be present at all in water supplies), (b) lithium, copper & zinc (chemicals for which definite objectives are set in water supplies), and (c) water hardness (which can change the toxic effect of the above chemicals). The objectives for lithium, copper and zinc are set out in "Canadian Drinking Water Standards and Objectives - 1968", Queen's Printer, Ottawa, 1969.

Let us now consider these.

(a) Cadmium and Chromium: If one of these metals was detected (i.e., with a value greater than 0) more than once for a given system with 6 samples for each chemical (12 results), then

$$I_{tox} = 1.$$

If detected once or not at all,

$$I_{tox} = 0,$$

where I_{tox} is the sub-index for toxic metals.

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if detected once or not at all,

$$I_{tox} = 0$$

where I_{tox} is the sub-index for toxic metals.

(b) Lithium, Copper and Zinc: The limits for these metals based on the Canadian Drinking Water Standards are:

	<u>Acceptable</u>	<u>Objective</u>
Lithium	5.0	0.1
Copper	1.0	0.01
Zinc	5.0	1.0

These figures are in milligrams per litre of water.

There were 18 results (6 samples each) taken for these 3 metals. If more than 5 were greater than the acceptable limits, then

$I_{LCZ} = 1.0$ where I_{LCZ} is the sub-index for lithium, copper and zinc.

If more than 5 were greater than the objective, with 1 over the acceptable limit, then $I_{LCZ} = 0.5$. These two statements and related ones can be summarized in the following table for I_{LCZ} :

TABLE W4

<u>Number of Samples over Acceptable Limit</u>	<u>Number of Samples Over Objective</u>	<u>I_{LCZ}</u>
0	0	0
0	1 to 5	0.2
1	1 to 5	0.3
1	more than 5	0.5
2 to 5	more than 2	0.8
more than 5	more than 5	1

(c) Water Hardness: Since the degree of harmfulness of the metals discussed is higher in soft water, a sub-index of total water hardness I_H was devised. The following table shows the values adopted.

TABLE W5

<u>Total Hardness (in milligrams of calcium carbonate per litre)</u>	<u>I_H</u>
60 to 120 (hard water)	0
0 to 60 (soft water)	0.5

(b) Lithium, Copper and Zinc: The limits for these metals

based on the Canadian Drinking Water Standards are:

	Acceptable	Objective
Lithium	5.0	0.1
Copper	1.0	0.01
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acceptable limit, then $I_{LCZ} = 0.5$. These two statements and related

ones can be summarized in the following table for I_{LCZ} :

TABLE W4

I_{LCZ}	Number of Samples Over Objective	Number of Samples over Acceptable Limit
0	0	0
0.5	1 to 5	0
0.3	1 to 5	1
0.5	more than 5	1
0.8	more than 5	2 to 5
1	more than 5	more than 5

(c) Water Hardness: Since the degree of harmfulness of the

metals discussed is higher in soft water, a sub-index of total water

hardness I_H was devised. The following table shows the values adopted.

TABLE W5

I_H	Total Hardness (in milligrams of calcium carbonate per litre)
0	60 to 120 (hard water)
0.5	0 to 60 (soft water)

This shows the fact that the potential harmfulness of toxic metals in water is least when the hardness ranges from 60 to 120 milligrams per litre. The potential harmfulness increases when the hardness is outside that range. For very hard water (with total hardness greater than 120 mg/litre of calcium carbonate), I_H is set at 0.2, as the hardness itself can cause harmful effects.

The results for the 5 metals and the water hardness of municipal water supplies were then combined as follows:

$$I_{TM} = \sqrt{\frac{I_{tox}^2 + I_{LCZ}^2 + I_H^2}{3}} \quad (W6)$$

where I_{TM} is the trace metal sub-index.

For each county in Canada, the average sub-index I_{TMC} was found by weighting the index for each municipality by the population served by the water supply system. See Table 11 for details. For those parts of western Canada which do not have counties, census districts were used instead. Results of calculating the average trace metal sub-index I_{TMC} for each county or census district are shown in Fig. W12. The weighted national average of I_{TM} was 0.35.

Turbidity in Canadian Rivers

Turbidity, or the lack of clearness in water, can be caused by natural or man-made activities. If water is too turbid, it is more difficult to use in water treatment plants. Furthermore, excessive turbidity can be deleterious to aquatic life and have objectionable aesthetic effects. A water use suitability index based on turbidity in river water was constructed from data supplied by the Environmental

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$$I_{TM} = \sqrt{\frac{I_{Co} + I_{Cu} + I_{Pb} + I_{Zn} + I_{Mn}}{5}}$$

where I_{TM} is the trace metal sub-index.

For each county in Canada, the average sub-index I_{TMC} was found by weighting the index for each municipality by the population served by the water supply system. See Table II for details. For those parts of western Canada which do not have counties, census districts were used instead. Results of calculating the average trace metal sub-index I_{TMC} for each county or census district are shown in Fig. W12. The weighted national average of I_{TM} was 0.32.

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Management Service. These data covered 429 stations for the year 1971, and included 305 river basins in all provinces and territories.

There are, of course, many other properties of water which make it unsuitable for water supply or recreation; for example, bacterial contamination and toxic substances. However, only limited data are available on these pollutants for waterways in Canada. The turbidity index presented here cannot adequately substitute for a true suitability index, but can provide a useful introduction. The river basins corresponded to those in the industrial and municipal effluent index.

The objectives for constructing this suitability index were taken from "Guidelines for Water Quality Objectives and Standards", Technical Bulletin No. 67, Inland Waters Branch, Department of the Environment, 1972. Essentially the objectives used were in two parts: one objective concerned with the suitability of water for drinking, and the other with its suitability for contact recreation, such as swimming. Since it is not known which areas of which rivers could be or are used for drinking and/or contact recreation, it was decided to apply both objectives to all rivers. The objective for turbidity of water for drinking is of course more stringent than that for contact recreation, and is a maximum of 5 "Jackson Units". These units are a measure of the turbidity of the water. It should be noted that this objective applies strictly to those water treatment plants where only chlorination is used. However, the objective of 5 units is a convenient and accepted measure of water quality. For contact recreation, the objective is 50 Jackson units.

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These two standards were combined into one sub-index for turbidity I_{turb} that indicated the suitability of ambient waters as a source of supply for contact recreation. The drinking water suitability sub-index was called I_d . The available data were arranged in order of magnitude, so that the highest reading of turbidity for the year at a given station, the 90th percentile, 75th percentile, the 50th percentile and so on could be identified. To illustrate what the word "percentile" means, if the 90th percentile is 7 units, say, then 90% of all the readings are less than 7 units.

If the highest value for the year is 5 units or less, then $I_d = 0$, indicating ideal suitability as drinking water. If the 90th percentile was 5 or less (assuming that the first condition was not met), then $I_d = 0.2$. Gradually declining conditions are expressed in the following table:

TABLE W6

Percentile for which turbidity is 5 units or less	Value of Sub-Index I_d
100 (high for year)	0
90	0.2
75	0.4
50	0.6
25	0.8
10	1

Let's take an example to show how this table was used.

Suppose a station had 10 readings for the year, with a maximum turbidity reading of 52 units, a 90th percentile reading (the second highest of the 10) of 20 units, a 75th percentile reading (the 4th highest) of 4 units, and so on. Then neither the highest reading of the year nor the 90th percentile were 5 units or less. However, the reading for the 75th percentile was less than 5, so that the value of I_d from the

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TABLE 16

Percentile for which turbidity is 5 units or less	Value of Sub-index I_{d}
100 (high for year)	0
90	0.2
75	0.4
50	0.6
25	0.8
10	1

Let's take an example to show how this table was used. Suppose a station had 10 readings for the year, with a maximum turbidity reading of 25 units, a 90th percentile reading (the second highest of the 10) of 20 units, a 75th percentile reading (the 4th highest) of 15 units, and so on. Then neither the highest reading of the year nor the 90th percentile were 5 units or less. However, the reading for the 75th percentile was less than 5, so that the value of I_{d} from the

previous table is 0.4. It should be noted that this method takes into account all the turbidity data as well as their distribution due to seasonal effects. An index based solely on the high for the year and/or the 50th or median percentile would give a bias towards either extreme conditions or exclude them entirely.

To determine the suitability of water for contact recreation, exactly the same procedure as above was followed except that an objective of 50 units of turbidity was substituted for 5 units. As an example, take the station discussed above. The criterion of 50 units or less was not met for the highest reading of the year, but it was met for the 90th percentile reading. Thus the sub-index I_{cr} of suitability for contact recreation is 0.2.

Since it was judged that the drinking water and contact recreation suitability sub-indices will have approximately equal value in constructing an overall index for turbidity, they were given equal weight in the combination of the two indices. Thus:

$$I_{turb} = \sqrt{\frac{I_d^2 + I_{cr}^2}{2}} \quad (W7)$$

where I_{turb} is the total suitability sub-index for turbidity.

Values of I_{turb} for each station in a basin were then averaged linearly for each river basin, to produce $I_{turb\ av}$. In other words, the weighting scheme of Table II was not used, because we do not know the distribution of flow rates of the particular river, nearby populations, etc. All of this information would be necessary to devise a more refined weighting scheme.

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A map of the sub-index for turbidity showing average suitability $I_{\text{turb av}}$ is contained in Fig. W13. To compute the provincial average of the turbidity index, we averaged the index I_{turb} for all the stations in the province, again without weighting one station more than another. A map of the turbidity index averaged provincially, $I_{\text{turb p}}$, is shown in Fig. W14. The average value for all Canada was 0.33.

Commercial Fisheries

Data on fish were gathered by the Fisheries and Marine Science Service. Fish are an "integrator" of environmental pollutants. In other words, they accumulate pollutants which might not otherwise be noticed. For example, mercury levels in fish are always higher than in the surrounding water. Data on mercury in fish were in two forms: (a) major fishing areas closed or under restrictions due to excessive mercury, and (b) mercury levels in fish landed from Canadian ships.

The first set of data is shown in Fig. W15. It was not possible to put this in the form of an index, since the total shoreline of all fishing areas, which would be required to construct such an index, is not known. However, the information is presented here for general information.

The second part of the data, that on actual mercury levels, was taken from "Mercury in Freshwater and Marine Fishes, Review of Action to November, 1971", Environment Canada, Ottawa, 1971. Data were included on 25 species of fish with a total landing in 1970 of about 1,254,000 tons. A total of 7,700 analyses were made for mercury in these fish.

A map of the sub-index for turbidity showing average sub-index 1_{turb av} is contained in Fig. W13. To compute the provincial average of the turbidity index, we averaged the index 1_{turb} for all the stations in the province, again without weighting one station more than another. A map of the turbidity index averaged provincially, 1_{turb p}, is shown in Fig. W14. The average value for all Canada was 0.33.

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To determine an index, the standard set by the Department of National Health and Welfare for the maximum level of mercury in the edible portion of fish intended for human consumption was used. This standard is 0.5 parts per million (ppm). Then the index of mercury in fish was

$$I_{\text{fish}} = \frac{W_1 C_1 + W_2 C_2 + W_3 C_3 + \dots}{0.5 (W_1 + W_2 + W_3 + \dots)} \quad (\text{W8})$$

where $W_1, W_2, W_3, \dots$ refer to the weights landed of each particular species of fish, and $C_1, C_2, C_3, \dots$ are the respective concentrations of mercury in each particular species, in parts per million (ppm). The number 0.5 refers to the standard in ppm noted above.

To see how this equation works, let us take a partial example. The following table shows the type of computations used:

TABLE W7

Species	Landings (1970): in 1000 lb. (W)	Average Mercury Level, ppm (C)
Cod	495,000	0.12
Haddock	49,000	0.06
Redfish	244,000	0.09

Then

$$I_{\text{fish}} = \frac{495,000(0.12) + 49,000(0.06) + 244,000(0.09)}{0.5(495,000 + 49,000 + 244,000)}$$

$$= \frac{84,300}{0.5 (788,000)} = 0.214$$

Using this method for all the 25 species, we find

$$I_{\text{fish}} = 0.210.$$

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Combined Ambient Water Quality Index

It was decided to give each of the three components of the ambient water quality index equal weight. We then have

$$I_{amb} = \sqrt{\frac{I_{TM}^2 + I_{turb\ t}^2 + I_{fish}^2}{3}} \quad (W9)$$

where I_{amb} is the ambient index, I_{TM} is the average index for trace metals, $I_{turb\ t}$ is the average turbidity index, and I_{fish} is the average index for mercury in fish. Using the values noted above, we have

$$\begin{aligned} I_{amb} &= \sqrt{\frac{(0.35)^2 + (0.33)^2 + (0.21)^2}{3}} \\ &= 0.30 \end{aligned}$$

III Combined Water Quality Index

Because the effluent and ambient water quality indices were judged to have approximately equal weight in an overall water quality index, the equation adopted for integrating these sub-indices was as follows:

$$\begin{aligned} I_{water} &= \sqrt{\frac{I_{lt}^2 + I_{amb}^2}{2}} \quad (W10) \\ &= \sqrt{\frac{(0.99)^2 + (0.30)^2}{2}} \\ &= 0.73. \end{aligned}$$

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$$I_{amb} = \sqrt{\frac{I_{TM}^2 + I_{turb}^2 + I_{fish}^2}{3}} \quad (W9)$$

where I_{amb} is the ambient index, I_{TM} is the average index for trace metals, I_{turb} is the average turbidity index, and I_{fish} is the average index for mercury in fish. Using the values noted above, we have

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III Combined Water Quality Index

Because the effluent and ambient water quality indices were judged to have approximately equal weight in an overall water quality index, the equation adopted for integrating these sub-indices was as follows:

$$I_{water} = \sqrt{\frac{I_{eff}^2 + I_{amb}^2}{2}} = \sqrt{\frac{(0.99)^2 + (0.30)^2}{2}} = 0.73 \quad (W10)$$

INTERPRETATION

Because of the nature of the data used in compiling this national water quality index, the maps shown in this section may vary considerably in appearance from those in the air quality section. This is because we have data from hundreds of sources, rather than dozens as in the discussion of the air quality index. To give a reasonable representation of the data, it was sometimes found useful to amalgamate on the basis of counties (in western Canada, census districts), as shown in Fig. W12.

As was explained in the Methodology, some data were available on a provincial or regional basis only, and these were therefore mapped accordingly. Furthermore, the "county" data were amalgamated into provincial averages, as shown in Fig. W14. It should be noted that Fig. W13, dealing with the turbidity index $I_{\text{turb av}}$, was drawn on the basis of averages over river basins rather than counties.

To recapitulate the discussion in the Methodology, the data were broken down into two broad sections, one dealing with discharges into water (Figs. W2 - W11), and one dealing with the ambient water environment, including secondary effects of water pollution (Figs. W12 - W15). Now let us discuss the data and the indices which were computed from them. In order to interpret properly the results dealing with discharges into water, we have to understand the assumptions on which they were based. Many of the latter are contained in Table W1, which lists the weights which were given to the waste constituents. We note that some waste constituents have high weights, although for

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some of the 5 sectors mentioned in the Methodology they are not now being measured. This, for the most part, is because an understanding of the process and thus the likely contaminants would not lead one to suspect their presence.

The maps are divided into two groups: those dealing with (a) the unit load index and (b) the total load index. In spite of the similarities in the names, they represent different quantities. The unit load index shows the effluent loadings in relation to quantities of materials processed or population served (as in the municipal sector).

In other words, this index generally indicates pollution clean-up efforts.

On the other hand, the total load index is a measure of the total quantity of waste constituents which are discharged from a particular sector. Obviously, if a given geographical area has a high population or concentration of industrial plants, its total load index will be higher than that of other areas with low population or which lack industrialization, if the degree of treatment is the same for both areas.

With this in mind, let us look at Fig. W2 showing the unit load index for municipalities. We see that Ontario, Manitoba and Alberta have the lowest (best) values of the unit load index, whereas the highest values are found in British Columbia, Quebec, Nova Scotia and Newfoundland. The central provinces, by this calculation, tend to have the lowest values of this index. However, no province has a value of the index greater than 1.2.

Fig. W3 shows the total load index for the municipal sector. Because of their large populations served by municipal waste treatment plants, Ontario and Quebec have the highest values of the index. The lowest values are in the Maritime Provinces, Manitoba and Saskatchewan.

In Fig. W4 we begin the series on the 4 industrial sectors. This map deals with the unit load index for the pulp and paper sector. We see that Nova Scotia and New Brunswick had the highest values of the index, followed by Ontario, Quebec and Newfoundland. The western provinces generally had lower values. Note that the scale of this graph is larger than that for municipalities. In other words, the scale for the 4 lowest categories of the index ranges from 0 to 1.2, whereas the scale for municipalities is from 0.8 to 1.2. It is recognized that the unit load from sulfite plants will be higher than the unit load for kraft plants. However, this degree of refinement was not considered in this publication.

The next map, Fig. W5, takes account of the concentration of this industrial sector in some provinces. The highest values of the total load index for the pulp and paper sector are now found in Ontario and Quebec, with all other provinces having considerably lower values.

It may have been noticed in the preceding maps that certain provinces and territories are shown in some, and not in others. This is because data were available for some of the 5 sectors, and not for others. Where no data were available, the corresponding geographical units were left blank.

Fig. W6 shows the unit load index for petroleum refining. We see that the Maritime Provinces (except Prince Edward Island which has no refineries) and Manitoba have the highest values. Most of the western Provinces, the Northwest Territories and Ontario have considerably lower values again; note that the scale for this map is different from those of corresponding maps for the 2 previously discussed sectors. It ranges, for the 4 lowest categories of the index, from 0 to 1.6, a larger range than that for the other two maps. This larger range was chosen so as to bring out the differences among areas more clearly.

Fig. W7 shows the total load index for the petroleum refining sector. The highest values are again in the Maritime Provinces, but in this case Quebec also has a relatively high value. Almost all of the rest of Canada has low values.

For the fish processing industry, it was not possible to prepare a unit load index, due to lack of data. However, the total load index, shown in Fig. W8, shows wide differences from province to province. Quebec has the highest value, followed by British Columbia and Newfoundland. On the other hand, the Prairie Provinces, Ontario, Northwest Territories and Prince Edward Island have relatively low values of this index.

Figs. W9 and W10 deal with the chlor-alkali industry. Because of the large decreases in the amount of mercury discharged into waters between 1969 and 1972, through pollution abatement activities, the values of the unit load index and total load index were uniformly low for the whole country. It will be recalled from the Methodology that,

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of the large decreases in the amount of mercury discharged into waters between 1959 and 1973, through pollution abatement activities, the values of the unit load index and total load index were uniformly low for the whole country. It will be recalled from the methodology that,

when data from a "base year" were available, they were used as a basis of comparison for the latest data. In this case, the base year values were high and reductions in loadings since the base year have been significant. This produces low indexes at this time. However, these low values should not be interpreted to mean that a problem with mercury no longer exists in Canada. We still have a problem which tends to be local rather than regional in nature.

Fig. W11 shows the total load index for each of the 131 river drainage basins, for the combined total effluents of the 5 sectors discussed above. Since data were not available for all basins, some were left blank. One should also remember that some current low indices may not remain low when effluent data from additional industrial sectors become available.

Because of the great amount of detail in this map, it is not possible to discuss each basin completely. However, in the Maritime Provinces, the basins with the highest value of the total load index are in northern Newfoundland, western Nova Scotia and western New Brunswick. Basins with low values are in Prince Edward Island, eastern New Brunswick, and Labrador.

In Quebec, most of the basins in the upper St. Lawrence Valley have high values. This region of high values of the total load index extends north and west from Montreal, with few exceptions. On the other hand, basins in the northwestern part of the province and along both sides of the lower St. Lawrence Valley have comparatively low values of the total load index.

Most of the basins in the Prairie Provinces have low values of the total load index. The highest values extend from extreme southern Manitoba into central Saskatchewan. There are also isolated basins with high values in northern and southern Alberta.

Southern British Columbia has relatively high values of the total load index, with the basins containing Vancouver Island and Vancouver the highest. The northern part of the province has low values, with the exception of one basin in the northwest portion. The Northwest Territories have only three basins for which data are available, and these all have low values of the index.

Of course, since in Fig. W11 we have been describing only the total load index, the highest values will tend to be concentrated in those basins with a high population being served by municipal sewage treatment plants, or with a large number of industries in the 4 sectors mentioned above. However, we can see differences between basins with comparable populations and industries, depending on the degree to which their effluent are treated before being discharged.

The average national value for I_{et} , the overall effluent loading index, was 0.99.

Fig. W12 shows the average sub-index of trace metals in municipal water supplies for counties and census districts I_{TMC} as computed from equation (W6). In general, this index is fairly low throughout the country, with most values of 0.4 or less. However, there is at least one county in each province (except Nova Scotia) in which the sub-index is 0.6 or above. Manitoba, Ontario, Quebec, New Brunswick and Newfoundland have two of these counties or census districts

with relatively high values of I_{TMC} . While provincial averages were not computed for this sub-index, it is clear that the average sub-index across Canada is within a low range, except for about a dozen counties where the index is considerably higher than the average.

In Fig. W13, the turbidity index $I_{turb\ av}$ for river basins in Canada is shown. As mentioned above, the turbidity index was compiled by taking into account suitability for both drinking water and contact recreation. Because of the differing natures of Canadian rivers, the index varies considerably across Canada. In all the Maritime provinces, for example, the index is very low. The index is also low throughout Quebec and Ontario, with the exception of some basins in Northern Ontario, the Windsor-Hamilton Corridor, and near Quebec City, where it rises to relatively high values, due probably to higher erosion in those areas. The Prairie Provinces tend to have higher values of the index, primarily in the southern and western portions of this region, where there are considerable natural sediment loads in rivers. In eastern Manitoba and the north-central portions of this region, the index of turbidity is very low. Waters in British Columbia are generally low in turbidity, with the exception of some northern basins and two basins on the lower mainland near Vancouver. The eastern Northwest Territories have very low values of the index but the western part of these Territories, as well as the Yukon Territory, have relatively high values.

In Fig. W14, the turbidity index $I_{turb\ av}$ has been averaged on a provincial basis. As expected on the basis of Fig. W13, where the data were shown by river basins, the western Provinces and the

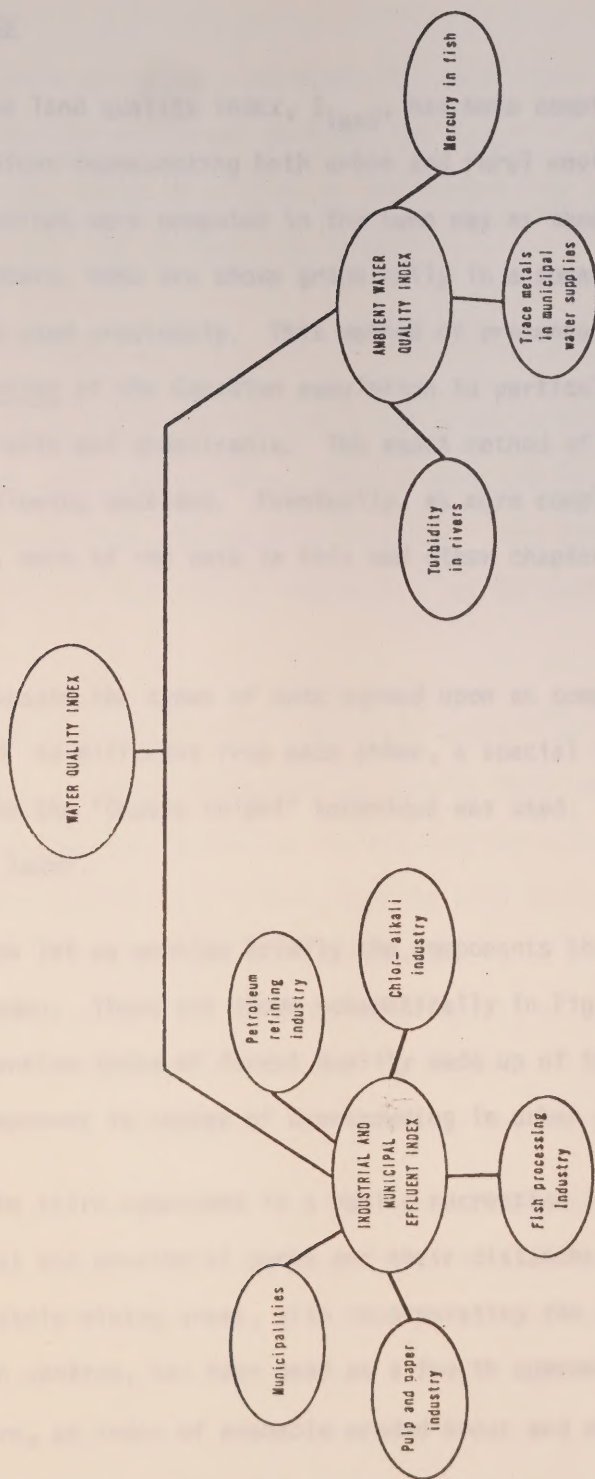
Territories have the greatest values of this index. In particular, Alberta has the highest provincial value. British Columbia, Quebec and Ontario have low values, and the Maritime Provinces have very low values.

In Fig. W15, we show data on areas closed or restricted due to excessive mercury in water. It was not possible to construct this information into an index, but we see large areas closed, primarily in Manitoba, Ontario and Quebec. Many of the areas are near highly populated sections of Canada.

The ambient water quality sub-indices were combined by giving each of the three the same relative importance. The average value of this index was then 0.30.

Since it was judged that the ambient and effluent indices were of approximately equal importance in an overall water quality index, they were given equal weight in its computation. The final average value for this index is then 0.73.

FIG. W1



LAND QUALITY INDEX

Methodology

The land quality index, I_{land} , has been compiled from a wide variety of sub-indices representing both urban and rural environments. Although the sub-indices were computed in the same way as those shown in the air and water chapters, some are shown graphically in a somewhat different manner from those used previously. This method of presentation takes account of the perception of the Canadian population to particular environmental qualities, both desirable and undesirable. The exact method of computation is explained in the following sections. Eventually, as more complete national data become available, more of the data in this and other chapters will be presented in this form.

Because the types of data agreed upon as components for a land quality index were so different from each other, a special technique of weighting them called the "Double Delphi" technique was used. This technique will be explained later.

Now let us mention briefly the components that make up the land quality index. These are shown schematically in Fig. L1. First, we have used a comprehensive index of forest quality made up of three sub-indices. The second component is degree of overcrowding in urban areas.

The third component is a public recreation index defined in terms of national and provincial parks and their distances to population centers. An index of strip mining areas, also incorporating the effect of distances to population centres, has been used as a fourth component. With respect to agriculture, an index of probable eroded areas and an index of high sediment-

carrying rivers are shown. Although this last index could be thought of as primarily dealing with water quality, the degree of sedimentation is a strong measure of the degree of erosion of the surrounding land. Each of these sub-indices will now be discussed in detail.

I Forestry Index

Forests provide the ecological zones essential for clean air and water. They modify our climate. They protect our watersheds from erosion, stabilize stream-flow and minimize flooding. They provide the scenic background for much of our outdoor recreation and the habitat for a wide variety of wildlife.

Because of the many viewpoints concerning forests, it is difficult to synthesize a common philosophy on judging their environmental quality. After much discussion, three sub-indices dealing with aspects of total forest environmental quality were chosen, dealing with the maintenance of forests, fire damage, and insect and disease damage. Three other sub-indices, dealing with the age structure of forests, the diversity of tree species in the forests and changes in the total area of the forest were considered, but were omitted due to lack of suitable data. Each of these two groups are explained below.

With almost all of the sub-indices mentioned, it would have been advantageous to have the forest data grouped by natural regions and districts of vegetation. Instead, they are usually compiled by provinces, leading to pooling of not wholly compatible data, and making it more difficult to interpret the indices which are computed from them. Furthermore, since many aspects of forest environmental quality are local or regional in nature,

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changes in one or a small number of areas tend to be submerged in provincial data.

Before discussing the three sub-indices which were chosen to constitute a forestry index, let us say a few words about those which could not be included at this time.

The purpose of the sub-index dealing with age structure of forests would have been to show how well the actual depletion of forest cover from all causes approaches the area of forest that should be converted each year to new young forest, to keep a healthy balance of different age classes. This sub-index is related to but not exactly the same as a sub-index of forest diversity.

This latter sub-index would have attempted to give a measure, on a regional basis, of the richness of the tree species mixture. A forest composed of many species is ecologically more stable, less prone to disastrous outbreaks of insects or disease, more scenic and more attractive to wildlife than a monotonous forest composed of only a few tree species.

Finally, a sub-index is needed to show the elimination of forest land arising from water impoundments, high-voltage electrical lines and road construction, urban sprawl, clearing of land for agriculture, etc., as well as additions arising from abandonment and reforestation of farm lands.

In the following sections, the data for forested areas which serve as the basis for calculation are those published in "Canadian Forest Statistics, 1970" (Statistics Canada, Ottawa, 1972). All the sub-indices were calculated for the following 4 regions and for Canada as a whole: British Columbia and

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and Alberta; Saskatchewan and Manitoba; Ontario and Quebec; and New Brunswick, Nova Scotia, Newfoundland and Labrador. Prince Edward Island was omitted completely because of lack of data. Data for the Yukon and Northwest Territories are included only in the fire sub-index, because there is very little commercial forestry at present in the Territories, whereas fire is an important factor there in the forest environment.

Now we shall discuss the three components of the forest environmental quality index.

A. Maintenance of Forest Resources

This indicates how much of the area is cut, burned, destroyed by insects and disease or otherwise depleted of its forest cover is regenerated back to productive forest. If the index is 0, all areas depleted are regenerated; if it is 1, none of the area is regenerated. Data for this and the following sub-index were from provincial returns and compiled by the Canadian Forestry Service, for the year 1970.

The formula used was

$$I_{fm} = \frac{D-R}{D} \quad (L1)$$

where D is the total productive forest area depleted annually from all sources, and R is the total productive forest regenerated annually. By "productive forest", we mean forest land suitable for regular harvest of wood under present standards of utilization.

In calculating the values for each region, it was assumed that the rate of the regeneration of the burned-over areas was the same as that

and Alberta; Saskatchewan and Manitoba; Ontario and Quebec; and New Brunswick, Nova Scotia, Newfoundland and Labrador. Prince Edward Island was omitted completely because of lack of data. Data for the Yukon and Northwest Territories are included only in the life sub-index, because there is very little commercial forestry at present in the Territories, whereas fire is an important factor there in the forest environment.

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where D is the total productive forest area depleted annually from all sources, and R is the total productive forest regenerated annually. By "productive forest", we mean forest land suitable for regular harvest of wood under present standards of utilization.

In calculating the values for each region, it was assumed that the rate of the regeneration of the burned-over areas was the same as that

of the logged areas, and that areas depleted by insects and disease were completely restocked with tree seedlings.

The latter assumption is well founded, the former may or may not be.

Depletion from insects, disease and other causes was calculated by the area in which 10% or more of the stand was killed in an area totalling 50 square miles or more. The total area affected was then multiplied by the percentage kill to make it equivalent to 100% depletion on the reduced acreage.

In order to determine a Canadian national average value for this sub-index, the values for each of the 4 regions was weighted by the relative area of (productive) forest land in that region. This gave a greater weight to the regions of Ontario and Quebec, and British Columbia and Alberta, since between them they have about 80% of the productive forest land in Canada. This weighting could be written mathematically as

$$I_{fmt} = \frac{A_{p1} I_{fm1} + A_{p2} I_{fm2} + A_{p3} I_{fm3} + A_{p4} I_{fm4}}{A_{pt}}$$

where I_{fmt} is the average Canadian value of I_{fm} , A_{p1} is the productive forest land in the first region, A_{p2} in the second region, and so on, and I_{fm1} is the value of I_{fm} in the first region, I_{fm2} in the second region, and so on.

Results are shown in Fig. L2. It should be noted that there is

of the logged areas, and that areas depleted by insects and disease were completely restocked with tree seedlings.

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not be.

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$$I_{\text{mt}} = \frac{A_1 I_{\text{mt}_1} + A_2 I_{\text{mt}_2} + A_3 I_{\text{mt}_3} + A_4 I_{\text{mt}_4}}{A_{\text{pt}}}$$

where I_{mt} is the average Canadian value of I_{mt} , A_1 is the productive forest land in the first region, A_2 in the second region, and so on, and I_{mt_1} is the value of I_{mt} in the first region, I_{mt_2} in the second region, and so on.

Results are shown in Fig. 12. It should be noted that there is

some overlap in coverage between this sub-index and the following two. However, because of the mathematical way in which the three were formulated, this is expected to be small.

B. Fire Damage

This sub-index indicates the area burned over annually in relation to certain criteria set for "maximum allowable burn" (MAB). For a fuller discussion of this concept, see the article in the journal Forestry Chronicle, vol. 25, p. 82-106 (1949), entitled "An outline of forest fire protection standards", by H.W. Beall. To summarize it briefly, the formula for MAB takes into account factors like (1) value of forest for wood production, watershed protection, recreation and wildlife; (2) degree of fire damage to forest and soil; (3) ease of re-establishment of forest after fire; (4) fuel hazards before fire; and (5) accessibility, climate and topography. In establishing the criteria, Canada was divided into 13 fire zones based largely on average precipitation during the fire season. Further details are discussed in the Interpretation.

In calculating the MAB, "non-productive forest" and "associated wildlands" were also taken into account. There is insufficient wood in non-productive forests to make them commercially usable, but the term does not imply that the lands are valueless from an ecological point of view. The "associated wildland" includes very sparsely treed land, muskeg and barren intimately associated with forest land.

The fire damage sub-index was defined as

$$I_{ff} = \frac{A_B}{A_{MAB}} \quad (L2)$$

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The fire damage sub-index was defined as

$$I_{FD} = \frac{A}{A_{MAB}}$$

where A_B is the total area burned in 1970 in the three categories noted above, and A_{MAB} is the area of maximum allowable burn. Results are shown in Fig. L3. Data used was compiled from provincial returns by the Canadian Forestry Service.

C. Forest Insect and Disease Damage

This sub-index deals with the unsightliness of forests resulting from outbreaks of insects and disease that do not necessarily kill trees. "Insect " and "disease" are used in the broadest sense to include everything affecting the appearance of trees, except fire and cutting, on forest land. It does not include the effects of insects or diseases on shade trees in urban or rural areas; nor does it include the effect of pests, such as decay organisms, which may lower the economic value of forest trees but not change their appearance.

The sub-index was calculated as follows:

$$I_{fp} = \frac{A_{fp}}{A_t} \quad (L3)$$

where A_{fp} is the total area of forest land rendered unsightly by insects and disease, and A_t is the total area of forest land.

In the calculations, only damage equivalent of that of a moderate to severe outbreak of spruce budworm (30% or more defoliation) and affecting a minimum area of 50 square miles for any one pest or disease was included.

Before being totalled, the areas affected were weighted by the percentage volume of the tree species affected of the total volume of all

where A_t is the total area burned in 1970 in the three categories noted above, and A_{max} is the area of maximum allowable burn. Results are shown in Fig. 13. Data used was compiled from provincial returns by the Canadian Forestry Service.

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The sub-index was calculated as follows:

$$I_{fp} = \frac{A_{fp}}{A_t} \quad (13)$$

where A_{fp} is the total area of forest land rendered unsightly by insects and disease, and A_t is the total area of forest land.

In the calculations, only damage equivalent to that of a moderate to severe outbreak of spruce budworm (30% or more defoliation) and affecting a minimum area of 50 square miles for any one pest or disease was included. Before being totaled, the areas affected were weighted by the percentage volume of the tree species affected of the total volume of all

tree species in the province. This was done because pests usually only attack certain species and not the whole forest. This can be written mathematically as

$$A_{fp} = \frac{A_1 V_1 + A_2 V_2 + A_3 V_3 + \dots}{V_T} \quad (L4)$$

where A_{fp} is the total provincial area used in equation (L3), A_1 is the area affected of the first tree species, A_2 of the second, and so on. V_1 is the total wood volume of the first tree species in that province, V_2 that of the second, and so on. V_T is the total wood volume of all species in that province.

Since overlaps of areas occurred in places with outbreaks of several pests, a breakdown of results in the absence of weighting could indicate that more than 100% of the forest was affected in certain localities. However, outbreaks also occur in forests of only one species, and a problem with the present weighting system is that tree species are not uniformly distributed throughout a province.

Results are shown in Fig. L4. Data were supplied by the Canadian Forestry Service, and refer to 1972.

D. Combined Forestry Environmental Quality Index

In view of the difficulty in allocating different relative importances to the three sub-indices mentioned above, it was decided to give equal weights. The combined forest environmental quality index is then

$$I_{for} = \sqrt{\frac{I_{fm}^2 + I_{ff}^2 + I_{fp}^2}{3}} \quad (L5)$$

tree species in the province. This was done because pests usually only attack certain species and not the whole forest. This can be written mathematically as

$$(L4) \quad A_{tp} = \frac{A_1 V_1 + A_2 V_2 + A_3 V_3 + \dots}{V_T}$$

where A_{tp} is the total provincial area used in equation (L3), A_1 is the area affected of the first tree species, A_2 of the second, and so on. V_1 is the total wood volume of the first tree species in that province, V_2 that of the second, and so on. V_T is the total wood volume of all species in that province.

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$$(L5) \quad I_{for} = \sqrt{\frac{I_{fm}^2 + I_{fs}^2 + I_{fp}^2}{3}}$$

where the terms on the right hand side are defined in equations (L1), (L2) and (L3). Using the values found there, we have

$$I_{\text{for}} = \sqrt{\frac{(0.20)^2 + (0.24)^2 + (0.09)^2}{3}} \\ = 0.19$$

Results of this calculation on a regional basis are shown in Fig. L5.

where the terms on the right hand side are defined in equations

(11), (12) and (13). Using the values found there, we have

$$I_{\text{for}} = \sqrt{\frac{S(0.20) + S(0.24) + S(0.02)}{3}} = 0.19$$

Results of this calculation on a regional basis are shown in

Fig. 12.

II Overcrowding in Cities

Because most of the sub-indices considered in the land quality index dealt with the rural or at least non-urban environment, it was decided to include sub-indices dealing with urban environments, if possible. The problem which posed itself here is that there were few if any "standards" available on this subject. One which was available, however, is that dealing with overcrowding in Canadian cities. Specifically, we used the Statistics Canada definition of overcrowding as being 1.01 or more persons per room living in a house. The definition was used in the CT series on the 1961 census. It was decided to take the fraction of overcrowded dwellings in 1961 as a temporary baseline. According to p. 30-1 of Statistics Canada Bulletin 2.2-2 for the 1961 census, this was $750,942/4,554,593 = 0.165$ of all dwellings. The numerator is the number of overcrowded dwellings, and the denominator is the total number of dwellings.

Because municipal data on the 1971 census were not yet available, it was decided to use the 1961 data. On comparison with previous censuses it was noted that the degree of overcrowding changed slowly with time. However, as soon as the data from the later census become available, they will be used.

The degree of overcrowding was computed only for the 17 census metropolitan areas noted in the census. Although non-metropolitan municipalities also had varying degrees of overcrowding in dwellings, they contained much rural or semi-rural environments. As a result, it was decided that their inclusion would have diluted what was essentially an urban sub-index.

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The index of overcrowded dwellings was

$$I_{cr} = \frac{D_{cr}}{0.165 D_t} \quad (L6)$$

where D_{cr} is the number of overcrowding dwellings in a metropolitan area, and D_t is the total number of dwellings in that area. The number 0.165 refers to the Canadian average of overcrowded dwellings, so that each metropolitan area is then compared to this average. Results of the computation are shown in Fig. L6.

To devise a national sub-index of overcrowding in Canadian cities, each city was weighted according to the number of dwellings in its metropolitan area. Then

$$I_{crt} = \frac{D_{t_1} I_{cr_1} + D_{t_2} I_{cr_2} + \dots}{D_{t_1} + D_{t_2} + \dots} \quad (L7)$$

where I_{crt} is the national index of overcrowding in Canadian cities; D_{t_1} , D_{t_2} , are the total number of dwellings in each of the 17 metropolitan areas, and I_{cr_1} , I_{cr_2} , are the indices of overcrowding for each of these areas, as computed by equation (L6). A total of 2,152,766 dwellings were considered in the computation of I_{crt} , or 47% of the 4,554,493 dwellings in Canada at that time. By these methods, the index I_{crt} was found to be 0.789.

III Eroded Areas

Because the exact locations of eroded areas in Canada are not known,

The index of overcrowded dwellings was

$$(16) \quad I_{CR} = \frac{D_{CR}}{0.165 D_T}$$

where D_{CR} is the number of overcrowding dwellings in a metropolitan area, and D_T is the total number of dwellings in that area. The number 0.165 refers to the Canadian average of overcrowded dwellings, so that each metropolitan area is then compared to this average. Results of the computation are shown in Fig. 16.

To devise a national sub-index of overcrowding in Canadian cities, each city was weighted according to the number of dwellings in its metropolitan area. Then

$$(17) \quad I_{CRN} = \frac{D_{T1} I_{CR1} + D_{T2} I_{CR2} + \dots}{D_{T1} + D_{T2} + \dots}$$

where I_{CRN} is the national index of overcrowding in Canadian cities; $D_{T1}, D_{T2}, \dots$ are the total number of dwellings in each of the 17 metropolitan areas, and $I_{CR1}, I_{CR2}, \dots$ are the indices of overcrowding for each of these areas, as computed by equation (16). A total of 2,125,766 dwellings were considered in the computation of I_{CRN} , or 47% of the 4,524,493 dwellings in Canada at that time. By these methods, the index I_{CRN} was found to be 0.789.

III Eroded Areas

Because the exact locations of eroded areas in Canada are not known,

an indirect method was used to find their probable locations. All data were supplied by the Soil Research Service of the Department of Agriculture.

First, estimates were made of the area of eroded land in each soil type in Canada. These estimates are shown in Table L1.

TABLE L1

Type of Soil	Area (Sq.Mi.)	Estimated Moderately to Severely Eroded Area (Sq. Miles)	Eroded Area as Percent of Area
Brown Chernozem	36,526	450	1.23
Dark Brown Chernozem	40,462	450	1.11
Black Chernozem	73,008	470	0.64
Dark Gray Chernozem	20,338	150	0.74
Solonchic	26,444	100	0.38
Gray Brown Luvisol	17,046	33	0.19
Gray Wooded Luvisol	277,743	350	0.13
Humo-Ferric Podzol	754,917	100	0.013

For those Canadian soils not listed, it was estimated that they contained no areas which were eroded. However, this estimation did not give us the location of these areas. To determine these, use was made of the fact that man-made erosion varied directly with the amount of use that

an indirect method was used to find their probable locations. All data were supplied by the Soil Research Service of the Department of Agriculture.

First, estimates were made of the area of eroded land in each soil type in Canada. These estimates are shown in Table I.

TABLE I

Type of Soil	Area (Sq. Mi.)	Estimated Moderately to Severely Eroded Area (Sq. Miles)	Eroded Area as Percent of Area
Brown Chernozem	36,826	480	1.23
Dark Brown Chernozem	40,462	450	1.11
Black Chernozem	73,008	470	0.64
Dark Gray Chernozem	20,338	120	0.74
Solonchak	26,444	100	0.38
Gray Brown Luvisol	17,046	33	0.19
Gray Wooded Luvisol	27,743	320	0.13
Humo-Ferric Podzol	764,917	100	0.013

For those Canadian soils not listed, it was estimated that they contained no areas which were eroded. However, this estimation did not give us the location of these areas. To determine these, use was made of the fact that man-made erosion varied directly with the amount of use that

is made of farmland. Use was then made of the map entitled "Broad Uses of Land, 1961", prepared by the Department of Agriculture. This map (not reproduced here) gave the percentage of cultivated land for all areas of Canada. Although the map is not current, the fraction of land used for agriculture changes very slowly.

To find the probable areas of eroded land, the above mentioned map and the Soil Map of Canada were overlaid. Then the fraction of cultivated land was multiplied by the fraction of potentially eroded land, found from Table L1, for each point on the map, to yield the fraction of probable eroded land. As an example, suppose that for a given point, 75% of the land in that area was cultivated, and the soil type was Black Chernozem, with 0.64% of the land estimated to be eroded for this soil type. Then the probable chance of erosion for that point is $0.75 \times 0.0064 = 0.0048$. The next problem to be faced was the construction of an index of erosion from these numbers, comparable in magnitude with those in other sub-indices in the Land Quality Index. This was done by giving an index of 1 to the point which had the highest probable chance of erosion in Canada. In the light of Table L1 this was an area with Brown Chernozem soil and 90% cultivation, yielding a probable chance of erosion of $0.0123 \times 0.9 = 0.0111$. The procedure of assigning an index I_{er} of probable erosion to the "probable chance" was then accomplished by multiplying the "probable chance" by $1/0.0111$, or 90. To summarize,

$$I_{er} = 90 L_{er} \times L_{cult} \quad (L8)$$

for each point in Canada, where L_{er} is the estimated fraction of eroded land for

is made of farmland. Use was then made of the map entitled "Broad Uses of Land, 1961", prepared by the Department of Agriculture. This map (not reproduced here) gave the percentage of cultivated land for all areas of Canada. Although the map is not current, the fraction of land used for agriculture changes very slowly.

To find the probable areas of eroded land, the above mentioned map and the Soil Map of Canada were overlaid. Then the fraction of cultivated land was multiplied by the fraction of potentially eroded land, found from

Table I, for each point on the map, to yield the fraction of probable eroded land. As an example, suppose that for a given point, 75% of the land in that area was cultivated, and the soil type was Black Chernozem, with 0.64% of the land estimated to be eroded for this soil type. Then the probable chance of erosion for that point is $0.75 \times 0.0064 = 0.0048$. The next problem to be faced was the construction of an index of erosion from these numbers, comparable in magnitude with those in other sub-indices in the Land Quality Index. This was done by giving an index of 1 to the point which had the highest probable chance of erosion in Canada. In the light of Table I, this was an area with Brown Chernozem soil and 90% cultivation, yielding a probable chance of erosion of $0.9123 \times 0.9 = 0.8211$. The

procedure of assigning an index I_{er} of probable erosion to the "probable chance" was then accomplished by multiplying the "probable chance" by $1/0.8211$, or 90. To summarize,

$$I_{er} = 90 \times \text{Cult} \times \text{Erosion} \quad (18)$$

for each point in Canada, where I_{er} is the estimated fraction of eroded land for

each soil type, and L_{cult} is the fraction of land cultivated at that point.

Results are shown in Fig. L7. For simplicity, averages have been taken for each county and census division (in Western Canada). Those counties or census divisions which had less than about 10% of their total land in cultivation were left blank. Other counties and census divisions which were left blank had $I_{er} = 0$.

A national index of probable soil erosion was then computed. This was done by weighting each county according to its area, and then multiplying that area by its index I_{er} . Thus

$$I_{ern} = \frac{A_1 I_{er_1} + A_2 I_{er_2} + \dots}{A_1 + A_2 + \dots} \quad (L9)$$

where I_{ern} is the national index of probable soil erosion; $A_1, A_2 \dots$ are the areas of counties or census divisions, and $I_{er_1}, I_{er_2} \dots$ are the respective indices of probable erosion. In this equation, cultivated areas with $I_{er} = 0$ were also included. We find $I_{ern} = 0.275$.

IV National and Provincial Parks

In this and the subsequent two sub-indices, use was made of a perception method of constructing indices. This took into account the distance of people from either environmental attractions or forms of land pollution.

The method was suggested by the Lands Directorate of the Department of the Environment, and is based on "Recreation Opportunity as an Indicator of the

each soil type, and I_{er} is the fraction of land cultivated at that point.

Results are shown in Fig. 17. For simplicity, averages have been

taken for each county and census division (in Western Canada). Those

counties or census divisions which had less than about 10% of their total

land in cultivation were left blank. Other counties and census divisions

which were left blank had $I_{er} = 0$.

A national index of probable soil erosion was then computed. This

was done by weighting each county according to its area, and then multiplying

that area by its index I_{er} . Thus

$$(19) \quad I_{ern} = \frac{A_1 I_{er1} + A_2 I_{er2} + \dots}{A_1 + A_2 + \dots}$$

where I_{ern} is the national index of probable soil erosion; $A_1, A_2, \dots$ are

the areas of counties or census divisions, and $I_{er1}, I_{er2}, \dots$ are the

respective indices of probable erosion. In this equation, cultivated areas

with $I_{er} = 0$ were also included. We find $I_{ern} = 0.272$.

IV. National and Provincial Parks

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The method was suggested by the Lands Directorate of the Department of

the Environment, and is based on "Recreation Opportunity as an indicator of the

Quality of Life", (Report for the Science Council of Canada, March, 1972). Although the resulting maps look somewhat different from those shown above, they give a more accurate portrayal of the actual effects on people's lives of environmental benefits or disbenefits.

Let's see how this method worked in practice. First the population "pressure" was computed. This was the imaginary "pressure" one would feel standing at a given point in Canada from the people in the rest of Canada. For example, the "pressure" of population one would feel in the middle of Northern Quebec would be much less than what one would feel near Montreal. One way of computing the total "pressure" at any point would be to let the "pressure" from each of the cities and towns in Canada drop off with distance. For example, suppose one was at a point 20 miles from Town A (population 10,000) and 50 miles from Town B (population 6,000). Then the "pressure" at that point is

$$\begin{aligned} P_p &= \frac{10,000 \text{ people}}{20 \text{ miles}} + \frac{6,000 \text{ people}}{50 \text{ miles}} \\ &= 500 \frac{\text{people}}{\text{mile}} + 120 \frac{\text{people}}{\text{mile}} \\ &= 620 \frac{\text{people}}{\text{mile}} \end{aligned} \tag{L10}$$

We can generalize this equation to take account of the "pressure" of population exerted by all cities and towns in Canada at a given point. (Actually, only those municipalities with populations greater than 5,000 were used). The population "pressure" at any point is

$$P_{\text{pop}} = \frac{P_1}{D_1} + \frac{P_2}{D_2} + \frac{P_3}{D_3} + \dots \tag{L11}$$

Quality of Life", (Report for the Science Council of Canada, March, 1972). Although the resulting maps look somewhat different from those shown above, they give a more accurate portrayal of the actual effects on people's lives of environmental benefits or disbenefits.

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$$p_{\text{pop}} = \frac{p_1}{D_1} + \frac{p_2}{D_2} + \frac{p_3}{D_3} + \dots \quad (L11)$$

where $P_1, P_2, P_3 \dots$ are the populations of the municipalities with over 5,000 people, and $D_1, D_2, D_3 \dots$ are their respective distances from this point. The "pressure" P_1 was found by computer for 676 evenly spaced grid points between 140° and 50° west longitude and 60° and 40° north latitude.

Because of the additional "pressure" put on Canadian national and provincial parks by visitors from the United States, the American influence was considered as a special factor for this sub-index. This was done by adding further terms to the right hand side of equation (L11) for those states part of whose territory lies within 400 miles of the Canadian border. The entire population of these states were used in these extra terms. Because the population of each of these neighbouring states included many municipalities, it was assumed for purposes of the calculation to be concentrated at the geographical center of the state. This method allowed a better assessment of population "pressure" on parks than by considering Canadian "pressure" only.

Now we found the "pressure" due to national and provincial parks. By analogy with the first example cited above, the parks "pressure" felt by someone near Banff or Jasper National Park is much greater than that felt near Montreal or Toronto. Again in accordance with what was said above, the parks "pressure" was assumed to fall off with distance. The problem now was how one weights the parks in analogy to the weighting of municipalities by their population. The simplest weight to choose was the actual land area of each park. If we had taken the number of visits to each park, for example, this would have already reflected to some degree

where $P_1, P_2, P_3, \dots$ are the populations of the municipalities with over 2,000 people, and $D_1, D_2, D_3, \dots$ are their respective distances from this point. The "pressure" P_j was found by computer for 676 evenly spaced grid points between 140° and 50° west longitude and 60° and 40° north latitude.

Because of the additional "pressure" put on Canadian national and provincial parks by visitors from the United States, the American influence was considered as a special factor for this sub-index. This was done by adding further terms to the right hand side of equation (11) for those states part of whose territory lies within 400 miles of the Canadian border. The entire population of these states were used in these extra terms. Because the population of each of these neighbouring states included many municipalities, it was assumed for purposes of the calculation to be concentrated at the geographical center of the state. This method allowed a better assessment of population "pressure" on parks than by considering Canadian "pressure" only.

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the population "pressure" on each park.

Before using the area of each park as a weight, there was one further point to be discussed. Because the sub-index of parks and recreation was constructed to show how the public perceived the availability of park land from different distances, the weighting of the park had to be done according to how the public perceived the area. This was done by using a law of psychology called Fechner's Law. This law states that the human response to a stimulus does not go up linearly, but rather logarithmically. What this meant in terms of park land was that the public generally could not perceive the difference in area between a given park and another 10% larger, say. When we take the natural logarithm of the area rather than just the area, the difference in public perception becomes clearer. For example; if we take two parks, one with ten times the area of the other, the perceived ratio of areas according to the logarithmic Fechner's law is about 3.3. Similarly, if the ratio of the areas of the two parks is 2.5, the perceived ratio is about 1.92, or 92% larger.

The practical effect of using Fechner's Law was to give more weight to the smaller parks, and less to the larger parks. We write

$$Y = \sum A_p \quad (L12)$$

where A_p is the park area in acres, and $\sum$ is the symbol for the natural logarithm. In analogy to equation (L11), the parks "pressure" at a given point in Canada was

$$P_{npp} = \frac{Y_1}{D_1} + \frac{Y_2}{D_2} + \frac{Y_3}{D_3} + \dots \quad (L13)$$

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$$(L12) \quad Y = \ln A_p$$

where A_p is the park area in acres, and $\ln$ is the symbol for the natural

logarithm. In analogy to equation (L1), the parks "pressure" at a given

point in Canada was

$$(L13) \quad p_{\text{pop}} = \frac{Y_1}{D_1} + \frac{Y_2}{D_2} + \frac{Y_3}{D_3} + \dots$$

where $Y_1, Y_2, \dots$ are the logarithms of the areas of each of the national and provincial parks in Canada, computed from equation (L12), and $D_1', D_2' \dots$ are the distances from the geographical centres of each of these parks to the point in question. Note that in general D_1' does not equal D_1 . The "pressure" P_{npp} was computed for the same 676 points previously mentioned.

In general, where the parks "pressure" was high and the population "pressure" was low, there was a high degree of accessibility to parkland. This could be defined in terms of a "proximity ratio",

$$R_a = \frac{P_{pop}}{P_{npp}} \quad (L14)$$

where P_{pop} and P_{npp} are the population and parks "pressure", respectively. Now the problem was to convert this proximity ratio into a sub-index of accessibility to national and provincial parks. The ratio itself could not be used for this purpose, because its units were complicated, and each sub-index had to be unitless.

The conversion was done by first "normalizing" the proximity ratio. In other words, the average ratio $R_{a_{av}}$ for all of the 676 points is found from

$$R_{a_{av}} = \frac{R_{a_1} + R_{a_2} + R_{a_3} + \dots}{676} \quad (L15)$$

where $R_{a_1}, R_{a_2}, R_{a_3} \dots$ are the accessibility ratios for each of the 676 points. Then each of the ratios was divided by $R_{a_{av}}$. We then have for the index of accessibility to national and provincial parks

where $Y_1, Y_2, \dots, Y_n$ are the logarithms of the areas of each of the national and provincial parks in Canada, computed from equation (11), and $D_1, D_2, \dots, D_n$ are the distances from the geographical centres of each of these parks to the point in question. Note that in general D_i does not equal D_j . The "pressure" P_{pop} was computed for the same 676 points previously mentioned.

In general, where the parks "pressure" was high and the population "pressure" was low, there was a high degree of accessibility to parks. This could be defined in terms of a "proximity ratio",

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The conversion was done by first "normalizing" the proximity ratio. In other words, the average ratio R_{av} for all of the 676 points is found from

$$(15) \quad R_{av} = \frac{R_{a1} + R_{a2} + R_{a3} + \dots + R_{a676}}{676}$$

where $R_{a1}, R_{a2}, R_{a3}, \dots, R_{a676}$ are the accessibility ratios for each of the 676 points. Then each of the ratios was divided by R_{av} . We then have for the index of accessibility to national and provincial parks

$$I_{acc} = \frac{R_a}{2R_{a_{av}}} = \frac{P_{pop}}{2P_{npp} R_{a_{av}}} \quad (L16)$$

The factor of 2 in the denominator was chosen so that the distribution of indices I_{acc} cluster around 0.5, which is midway between the 0 of "perfection" and the 1 of "just barely meeting standards" (as employed in other sub-indices). This approach was adopted since there were no standards at present with respect to park accessibility. Results are shown in Fig. L8. Contours were drawn between grid points which had equal values of I_{acc} to produce this map.

Next the national average of the index I_{acc} was found. If the average of all 676 grid points were found, it would be 0.5, for the reasons mentioned above. However, some of these points fall either at sea or outside Canadian borders. Since this chapter deals with Canadian land, only those points falling on it were considered in the average - 332 in all. The average national index of accessibility to national and provincial parks was then 0.418. It should be noted in conclusion that this index refers only to public parkland, and is not measure of scenic beauty, private parks, emptiness of land, or of other quantities which cannot be measured. Thus parts of Canada will have different values of I_{acc} from that which would be expected on the basis of a consideration of scenic beauty or emptiness. Furthermore, by "parkland" we do not necessarily mean a word synonymous with recreational opportunity. The exact relationship of parkland with recreation is difficult to write down mathematically.

V Strip Mining

The surface mining of minerals is generally considered to disfigure

(116)

$$I_{acc} = \frac{R_a}{\frac{R_a}{R_{pop}} + \frac{R_{pop}}{R_{av}}} = \frac{R_a}{\frac{R_a}{R_{pop}} + \frac{R_{pop}}{R_{av}}}$$

The factor of 2 in the denominator was chosen so that the distribution of indices I_{acc} cluster around 0.5, which is midway between the 0 of "perfection" and the 1 of "just barely meeting standards" (as employed in other sub-indices). This approach was adopted since there were no standards at present with respect to park accessibility. Results are shown in Fig. 18. Contours were drawn between grid points which had equal values of I_{acc} to produce this map.

Next the national average of the index I_{acc} was found. If the average of all 678 grid points were found, it would be 0.5, for the reasons mentioned above. However, some of these points fall either at sea or outside Canadian borders. Since this chapter deals with Canadian land, only those points falling on it were considered in the average - 332 in all. The average national index of accessibility to national and provincial parks was then 0.418. It should be noted in conclusion that this index refers only to public parkland, and is not measure of scenic beauty, private parks, emptiness of land, or of other quantities which cannot be measured. Thus parts of Canada will have different values of I_{acc} from that which would be expected on the basis of a consideration of scenic beauty or emptiness. Furthermore, by "parkland" we do not necessarily mean a word synonymous with recreational opportunity. The exact relationship of parkland with recreation is difficult to write down mathematically.

V Strip Mining

The surface mining of minerals is generally considered to disfigure

the landscape and so is included in this chapter. Data on the location and extent of strip mining in Canada were supplied by the Department of Energy Mines and Resources (Mineral Resources Branch). Generally, strip mining is confined to coal.

The index for strip mining I_{sm} was calculated in a similar manner to that for accessibility to parkland, i.e., by the perception method. Because this method shows clearly relationships between distances and populations, it is intended to put more of the Environmental Quality Index on this basis.

First, the population "pressure" P_{pop} (from equation(L11)) was used for each of the grid points mentioned above. Because there was no real "pressure" put on strip mining areas by visitors from the United States, for purposes of this sub-index U.S. population near the Canadian border was not included. Then the "pressure" of strip mining areas P_{sm} was computed in the same way as shown in equations (L12) and (L13) with the areas of strip mines taking the place of the areas of parks. The distances to the grid points were now $D_1', D_2', \dots$, where in general D_1' does not equal D_1 .

The proximity ratio for strip mining, R_s , was then constructed, in analogy to the proximity ratio R_a of equation (L14). However, in the computation of R_a the parks "pressure" P_{npp} was in the denominator so that as P_{npp} became larger, R_a became smaller. Because strip mining areas were viewed as an environmental problem instead of an environmental benefit (as are parks), the strip mining "pressure" in R_s was in the numerator, rather than the denominator. Then if for a grid point the strip mining "pressure" became larger, the proximity ratio would become larger, and the index for strip

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The proximity ratio for strip mining, R_{sm} , was then constructed, in analogy to the proximity ratio R_p of equation (14). However, in the computation of R_{sm} the parks "pressure" P_{pop} was in the denominator so that as P_{pop} became larger, R_{sm} became smaller. Because strip mining areas were viewed as an environmental problem instead of an environmental benefit (as are parks), the strip mining "pressure" in R_{sm} was in the numerator, rather than the denominator. Then if for a grid point the strip mining "pressure" became larger, the proximity ratio would become larger, and the index for strip

mining I_{sm} would also become larger. This is summarized by writing

$$R_s = \frac{P_{sm}}{P_{pop}} \quad (L17)$$

To determine an index I_{sm} for strip mining areas, the proximity ratio R_s was normalized in the same way that R_a was, to produce the average value of R_s .

Then

$$I_{sm} = \frac{R_s}{2R_{s_{av}}} = \frac{P_{sm}}{2P_{pop} R_{s_{av}}} \quad (L18)$$

Again, the average value of all the grid points was 0.5, for the reasons discussed above. When only the 332 points falling on Canadian land are considered, we have an average national index of strip mining areas $I_{sm} = 0.52$. Results of the computation are shown in Fig. L9.

VI Sedimentation in Rivers

As mentioned above, river sedimentation increases with the erosion of the surrounding land. So producing an index of sedimentation I_{sed} gives another measure of erosion of land. This index was computed by the perception method used in the previous two sections, for the reasons mentioned before.

Data on sedimentation were supplied by the Water Survey of Canada. Only those regions of Canada with the three highest categories of sedimentation were considered for this index. These three categories were those with

mining I_{sm} would also become larger. This is summarized by writing

$$R_2 = \frac{p_{sm}}{p_{pop}} \quad (17)$$

To determine an index I_{sm} for strip mining areas, the proximity ratio R_2 was normalized in the same way that R_1 was, to produce the average value of R_2 . Then

$$I_{sm} = \frac{R_2}{\overline{R_2}} = \frac{p_{sm}}{\overline{p_{sm}}} \quad (18)$$

Again, the average value of all the grid points was 0.5, for the reasons discussed above. When only the 335 points falling on Canadian land are considered, we have an average national index of strip mining areas $I_{sm} = 0.52$. Results of the computation are shown in Fig. 19.

VI Sedimentation in Rivers

As mentioned above, river sedimentation increases with the erosion of the surrounding land. So producing an index of sedimentation I_{sed} gives another measure of erosion of land. This index was computed by the perception method used in the previous two sections, for the reasons mentioned before.

Data on sedimentation were supplied by the Water Survey of Canada. Only those regions of Canada with the three highest categories of sedimentation were considered for this index. These three categories were those with

greater than 1,000, between 700 and 1,000, and between 400 and 700 the milligrams of sediment per liter of water. Weights for these three regions were adopted as follows:

TABLE L2

<u>Sedimentation (in milligrams of sediment per liter of river water)</u>	<u>Value</u>
more than 1,000	1
700 to 1,000	0.67
400 to 700	0.33
less than 400	0

Because some of the regions with relatively high sedimentation had large areas, each was broken up into segments of about 10,000 square miles each. Then each segment of these large regions was assigned a total weight proportional to its area. This procedure was also adopted for the smaller regions. An example of the procedure of finding the total weight for each region is shown in the following table.

TABLE L3

Region	Area (Sq. Mi.)	Sedimentation (mg/l)	Value of Sedimentation Weight (from Table L2)	Total Weight of Region = Value times Area
A	5,000	more than 1,000	1	5,000
B	2,000	500	0.33	660

greater than 1,000, between 700 and 1,000, and between 400 and 700 milligrams of sediment per liter of water. Weights for these three regions were adopted as follows:

TABLE 12

Sedimentation (in milligrams of sediment per liter of river water)	Value
more than 1,000	1
700 to 1,000	0.67
400 to 700	0.33
less than 400	0

Because some of the regions with relatively high sedimentation had large areas, each was broken up into segments of about 10,000 square miles each. Then each segment of these large regions was assigned a total weight proportional to its area. This procedure was also adopted for the smaller regions. An example of the procedure of finding the total weight for each region is shown in the following table.

TABLE 13

Region	Area (sq. mi.)	Sedimentation (mg/l.)	Value of Sedimentation Weight (from Table 12)	Total Weight of Region = Value times Area
A	2,000	more than 1,000	1	2,000
B	2,000	700	0.33	660

The geographical centre of each region was then found, and the total weight of each region was assumed to be concentrated at that place. Then the same procedure as was used in finding the strip mining "pressure" was adopted, with the total weights of the sedimentation regions taking the place of the areas of strip mines. Then

$$P_{sed} = \frac{Y_1'''}{D_1'''} + \frac{Y_2'''}{D_2'''} + \dots \quad (L19)$$

where Y_1''' , Y_2''' , are the logarithms of the total weight of the sedimentation regions and D_1''' , D_2''' , are the distances from their geographical centres to the 676 grid points. Note that in general, D_1''' does not equal D_1'' or D_1' . P_{sed} is the "pressure" due to sedimentation.

The population "pressure" P_{pop} at each grid point was the same that was computed from equation (L11). Then the "proximity ratio" for sedimentation was

$$R_{sed} = \frac{P_{sed}}{P_{pop}} \quad (L20)$$

As in the case of strip mining, the population "pressure" is the denominator, because regions of high sedimentation are viewed as an environmental problem rather than a benefit. The proximity ratio R_{sed} was normalized in the same way as were R_a and R_s in the two previous sections, to produce an average value of R_{sed} : $R_{sed_{av}}$. Then

$$I_{sed} = \frac{R_{sed}}{2R_{sed_{av}}} = \frac{P_{sed}}{2P_{pop} R_{sed_{av}}} \quad (L21)$$

The geographical centre of each region was then found, and the total weight of each region was assumed to be concentrated at that place. Then the same procedure as was used in finding the strip mining "pressure" was adopted, with the total weights of the sedimentation regions taking the place of the areas of strip mines. Then

$$(L19) \quad p_{sed} = \frac{Y_1''}{D_1''} + \frac{Y_2''}{D_2''} + \dots$$

where Y_1'' , Y_2'' , ... are the logarithms of the total weights of the sedimentation regions and D_1'' , D_2'' , ... are the distances from their geographical centres to the 676 grid points. Note that in general, D_j'' does not equal D_j' or D_j . p_{sed} is the "pressure" due to sedimentation.

The population "pressure" p_{pop} at each grid point was the same that was computed from equation (L1). Then the "proximity ratio" for sedimentation was

$$(L20) \quad R_{sed} = \frac{p_{sed}}{p_{pop}}$$

As in the case of strip mining, the population "pressure" is the denominator, because regions of high sedimentation are viewed as an environmental problem rather than a benefit. The proximity ratio R_{sed} was normalized in the same way as were R_1 and R_2 in the two previous sections, to produce an average

value of R_{sed} : $\bar{R}_{sed}$. Then

$$(L21) \quad I_{sed} = \frac{R_{sed}}{\bar{R}_{sed}} = \frac{p_{sed}}{p_{pop} \bar{R}_{sed}}$$

The average value of all the grid points was 0.5, for the reasons discussed in section IV. When only the 332 Canadian land points were considered, the average national index of sedimentation was $I_{\text{sed}} = 0.62$. Results are shown in Fig. L10, with contours drawn for equal values of I_{sed} .

VII Aggregation of the Land Quality Index

Because some data were not available on a localized basis, it was not possible to draw up a map of the combined land quality index, as was the case for the air quality index. However, the 6 average national sub-indices were combined into an average national index for land quality.

Because of the differences among the various types of data which were used, a special system to obtain their relative weights in the root-mean-square technique was used. This system was known as "Double Delphi". This consisted of the experts on the environmental quality of land on the committee independently suggesting weights for each of the sub-indices. Their numerical judgements were then averaged, and the results presented back to them for any changes they would suggest on further consideration. These second set of weights were then used as the final weights for the 6 sub-indices. It is seen that this "Double Delphi" system combines the advantages of independent judgement and consensus. The results of the two trials, scaled so that the largest weight is set equal to 1, are shown in the following table:

The average value of all the grid points was 0.5, for the reasons discussed in section IV. When only the 332 Canadian land points were considered, the average national index of sedimentation was $I_{sed} = 0.62$. Results are shown in Fig. 110, with contours drawn for equal values of I_{sed} .

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INTERPRETATION

TABLE L4

Sub-Index	First Average Weight (with 1 as maximum)	Second Average Weight (with 1 as maximum)
Forestry	0.74	0.68
Overcrowding	1.00	1.00
Erosion	0.50	0.46
Parks	0.76	0.76
Strip Mining	0.42	0.46
Sedimentation	0.46	0.36

We see from this table that the weights changed very little from the first trial to the second, indicating a general consensus had been reached on the relative importance of the 6 sub-indices. Using these weights in the root-mean-square technique, we have the total index of land quality:

$$\begin{aligned}
 I_{\text{land}} &= \sqrt{\frac{0.68(I_f)^2 + 1(I_{\text{crt}})^2 + 0.46(I_{\text{er}})^2 + 0.76(I_{\text{acc}})^2 + 0.46(I_{\text{sm}})^2 + 0.36(I_{\text{sed}})^2}{3.72}} \\
 &= \sqrt{\frac{0.68(0.19)^2 + 1(0.789)^2 + 0.46(.275)^2 + 0.76(.418)^2 + 0.46(.52)^2 + 0.36(.62)^2}{3.72}} \\
 &= 0.54
 \end{aligned}
 \tag{L22}$$

where the sub-indices I_{for} , I_{crt} , I_{ern} , I_{acc} , I_{sm} and I_{sed} deal with forestry, overcrowding, erosion, accessibility to parkland, strip mining and sedimentation respectively.

TABLE 1A

Sub-Index	First Average Weight (with I as maximum)	Second Average Weight (with I as maximum)
Forestry	0.74	0.63
Overcrowding	1.00	1.00
Erosion	0.50	0.46
Parks	0.76	0.76
Strip Mining	0.45	0.46
Sedimentation	0.46	0.36

We see from this table that the weights changed very little from

the first trial to the second, indicating a general consensus had been reached on the relative importance of the 6 sub-indices. Using these weights in the root-mean-square technique, we have the total index of land quality:

$$I_{\text{land}} = \sqrt{\frac{S_{\text{for}}^2 + 11I_{\text{crt}}^2 + 0.46(I_{\text{er}}^2 + 0.76(I_{\text{acc}}^2 + 0.46(I_{\text{sm}}^2 + 0.36(I_{\text{sed}}^2)))}{3.75}}$$

$$= \sqrt{\frac{0.68(0.74)^2 + 11(0.78)^2 + 0.46(0.76)^2 + 0.76(0.418)^2 + 0.46(0.52)^2 + 0.36(0.52)^2}{3.75}}$$

= 0.84 (L25)

where the sub-indices I_{for} , I_{crt} , I_{er} , I_{acc} , I_{sm} and I_{sed} deal with forestry, overcrowding, erosion, accessibility to parks, strip mining and sedimentation respectively.

INTERPRETATION

Because of the different types and treatment of data which were dealt with in this chapter, the maps which illustrate the various sub-indices vary considerably in the way they present the data. For example, the indices of the last three figures in this chapter were computed in terms of the perception of Canada's population of environmental benefits and problems, whereas the others (excluding Fig. L1, which is a schematic diagram), were not. However, it was shown in the preceding part of this chapter that the national averages of the sub-indices could be combined into a national index of land quality I_{land} .

As an introductory remark to the maps dealing with forests, only those areas of Canada actually forested were shown in colour. This accounts for the blank areas in the north and west of the following four maps.

Fig. L2 shows the variation in the maintenance of the forest resource across Canada. Saskatchewan and Manitoba have the highest value of the index, suggesting the lowest rate of regeneration of forest. Regeneration is more complete in the relatively moist eastern half of the country.

With the weighting by forest area described in the Methodology, the national average of the maintenance of resource sub-index was 0.20, suggesting a small net depletion of forest land. It should be noted, however, that the provinces and industry are currently planting or seeding about 300,000 acres of forest land annually, and this value is rising dramatically.

Interpreting the map and the national average of the sub-index is made more difficult for two reasons. First, a bad fire year can distort

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Interpreting the map and the national average of the sub-index is made more difficult for two reasons. First, a bad fire year can distort

trends by increasing the apparent area of unregenerated land. In 1970, Saskatchewan had a very bad fire year, and British Columbia a moderately severe one. Second, the difference between the estimates of areas of depletion and regeneration, from which we derive this sub-index, only indicate their values for a particular year. But regeneration is a continuing process. Given time, even large areas of burned or cut-over forest will return to a treed state.

What this sub-index does show is the relative success of forest management in holding fire losses to a minimum, and in regenerating either by man or by nature those and other areas which have been affected by cutting, fires, insects and disease.

In Fig. L3, we see the sub-index of forest fire damage. The highest values of the index are in Manitoba and Saskatchewan. The next highest value is in British Columbia and Alberta, although this latter value is considerably lower than the previous one. Other areas of Canada also have low values of this sub-index. The Canadian average value was 0.24.

To understand what this means, the following table puts the value in perspective:

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What this sub-index does show is the relative success of forest management in holding fire losses to a minimum, and in regenerating either by man or by nature those and other areas which have been affected by cutting, fires, insects and disease.

In Fig. 13, we see the sub-index of forest fire damage. The highest values of the index are in Manitoba and Saskatchewan. The next highest value is in British Columbia and Alberta, although this latter value is considerably lower than the previous one. Other areas of Canada also have low values of this sub-index. The Canadian average value was 0.54.

To understand what this means, the following table puts the value in perspective:

TABLE L5

	Total Area (thousands of acres)	Maximum Allowable Burn (MAB)	Area Burned in 1970 (thousands of acres)
Productive forest	588,000	881	1506
Non-Productive forest and wild land	683,000	9120	918
Total	1,271,000	10,000	2424

Most of the maximum allowable burn is allocated against non-productive forest and wild land, much of which is in northern or mountainous and inaccessible regions. It is apparent, however, that 1970 was a serious year for fire damage on productive forest land.

Even in areas well-protected by fire control agencies, burning conditions during the fire season determine whether Canada has a good or poor fire year. Prolonged periods of dry, windy weather can nullify the best efforts of fire control.

Fire is not always destructive. In some situations, it can be beneficial in promoting replacement of an "overmature" forest by a young, vigorous one, or in giving rise to a plant community that is more favorable for wildlife. However, the question is complex.

A future fire sub-index could take into account such factors as proximity of fires to cities, highways and recreation areas.

TABLE 13

Area Burned in 1970 (thousands of acres)	Maximum Allowable Burn (MAB)	Total Area (thousands of acres)	
1506	881	588,000	Productive Forest
978	9120	683,000	Non-productive Forest and wild land
2484	10,000	1,271,000	Total

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A future fire sub-index could take into account such factors as proximity of fires to cities, highways and recreation areas.

In Fig. L4, we see the sub-index for insect and disease damage. Because of the low values of this sub-index, a narrower scale was chosen to bring out differences. We see that only Quebec and Ontario had a value of this sub-index greater than 0.10. The values were not high because the areas affected were not large in comparison with the total forested areas in Canada. Much of the area damaged, however, was readily accessible to the public.

This first approach to a sub-index for insect and disease damage to the forest presents problems. First, it has not been possible to select a "standard" comparable to the Maximum Allowable Burn, which was used for the fire sub-index, so that it became necessary to use the total forest area as the basis for comparison. This results in a very low index number, which can be misleading because infestations tend to be concentrated and highly visible where they occur. Secondly, the pooling of the data on infestations for large regions tends to submerge further the occurrence of even major infestations within a portion of a larger region. As an illustration of these factors, the calculated indices for the Atlantic Provinces and for Quebec and Ontario, are 0.10 and 0.15, respectively, in spite of the fact that very large outbreaks of the spruce budworm occurred in these provinces (see section of 1972 infestations showing through the colourcode of New Brunswick, Quebec and Ontario.)

Some of the major insects and diseases were the spruce budworm (from Ontario to Newfoundland), birch defoliating insects (in the same area), the large aspen tortrix (from Saskatchewan to Quebec), and the Dutch elm disease (in Ontario and Quebec). Without major control programs for spruce

In Fig. 14, we see the sub-index for insect and disease damage.

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to the forest presents problems. First, it has not been possible to select a "standard" comparable to the Maximum Allowable Burn, which was used for the fire sub-index, so that it became necessary to use the total forest area as the basis for comparison. This results in a very low index number, which can be misleading because infestations tend to be concentrated and highly visible where they occur. Secondly, the pooling of the data on infestations for large regions tends to submerge further the occurrence of even major infestations within a portion of a larger region. As an illustration of these factors, the calculated indices for the Atlantic Provinces and for Quebec and Ontario are 0.10 and 0.12, respectively, in spite of the fact that very large outbreaks of the spruce budworm occurred in these provinces (see section of 1972 infestations showing through the colourcode of New Brunswick, Quebec and Ontario.)

Some of the major insects and diseases were the spruce budworm (from Ontario to Newfoundland), birch defoliating insects (in the same area), the large aspen tortrix (from Saskatchewan to Quebec), and the Dutch elm disease (in Ontario and Quebec). Without major control programs for spruce

budworm in New Brunswick, Quebec and Ontario, the values of the sub-index for these provinces would have been higher.

The Canadian average for this sub-index was 0.09.

Finally, the overall forest environmental quality index was computed by giving equal weight to each of the three sub-indices discussed above. The value of the combined index was 0.19, which was relatively low.

In Fig. L5, we see the values of this overall index on a regional basis. The Maritime provinces have the lowest value, followed by Ontario and Quebec. Saskatchewan and Manitoba have the highest value, due to the fire damage of 1970.

As a general remark upon the four preceding maps, we might note that the range of the colours shown does not necessarily imply that all of the coloured areas shown are completely forested. Many areas in each exist where there are no forests. The provincial averages are shown covering each province for the purpose of clarity and simplicity.

budworm in New Brunswick, Quebec and Ontario, the values of the sub-index for these provinces would have been higher.

The Canadian average for this sub-index was 0.03.

Finally, the overall forest environmental quality index was computed by giving equal weight to each of the three sub-indices discussed above. The value of the combined index was 0.19, which was relatively low. In Fig. 15, we see the values of this overall index on a regional basis. The Maritime provinces have the lowest value, followed by Ontario and Quebec. Saskatchewan and Manitoba have the highest value, due to the fire damage of 1970.

As a general remark upon the four preceding maps, we might note that the range of the colours shown does not necessarily imply that all of the coloured areas shown are completely forested. Many areas in each exist where there are no forests. The provincial averages are shown covering each province for the purpose of clarity and simplicity.

In Fig. L6, we see the index of overcrowded dwellings in metropolitan areas I_{cr} , derived from the Statistics Canada definition of overcrowding as being more than one person per room in a house.

To determine an index for the major cities in Canada, their percentage of overcrowded dwellings was compared to the national average. Generally, most western cities had low values of I_{cr} . This was also the case through southern Ontario. However, cities in northern Ontario, Quebec, and the Maritimes had relatively high values of the index. St. John's and Sudbury had the highest values among the major metropolitan areas treated.

Fig. L7 shows the index of probable regions of erosion I_{er} . Since it was not possible to determine the actual eroded areas in Canada, the index was found by an "overlay" method, in which the estimated eroded land as a function of soil type was multiplied by the degree of cultivation. The index is very low throughout all of eastern Canada and northern Alberta. Moderate values are seen in southern Manitoba and northern Saskatchewan. The highest values are found in western and southern Saskatchewan. Because of the varying soil type and degrees of cultivation, the data are presented on a census district classification. The average value of the index I_{er} was 0.275.

In Figs. L8, L9 and L10, the perception of certain environmental problems or benefits by the Canadian population is shown. To do this, we take into account the distances that population centres are from these problems or benefits. The exact method of computation was shown in the "Methodology" for this chapter.

In Fig. 16, we see the index of overcrowded dwellings in metropolitan areas I_{CP} , derived from the Statistics Canada definition of overcrowding as being more than one person per room in a house. To determine an index for the major cities in Canada, their percentage of overcrowded dwellings was compared to the national average. Generally, most western cities had low values of I_{CP} . This was also the case through southern Ontario. However, cities in northern Ontario, Quebec, and the Maritimes had relatively high values of the index. St. John's and Sudbury had the highest values among the major metropolitan areas treated.

Fig. 17 shows the index of probable regions of erosion I_{ER} . Since it was not possible to determine the actual eroded areas in Canada, the index was found by an "overlay" method, in which the estimated eroded land as a function of soil type was multiplied by the degree of cultivation. The index is very low throughout all of eastern Canada and northern Alberta. Moderate values are seen in southern Manitoba and northern Saskatchewan. The highest values are found in western and southern Saskatchewan. Because of the varying soil type and degrees of cultivation, the data are presented on a census district classification. The average value of the index I_{ER} was 0.232.

In Figs. 18, 19 and 20, the perception of certain environmental problems or benefits by the Canadian population is shown. To do this, we take into account the distances that population centres are from these problems or benefits. The exact method of computation was shown in the "Methodology" for this chapter.

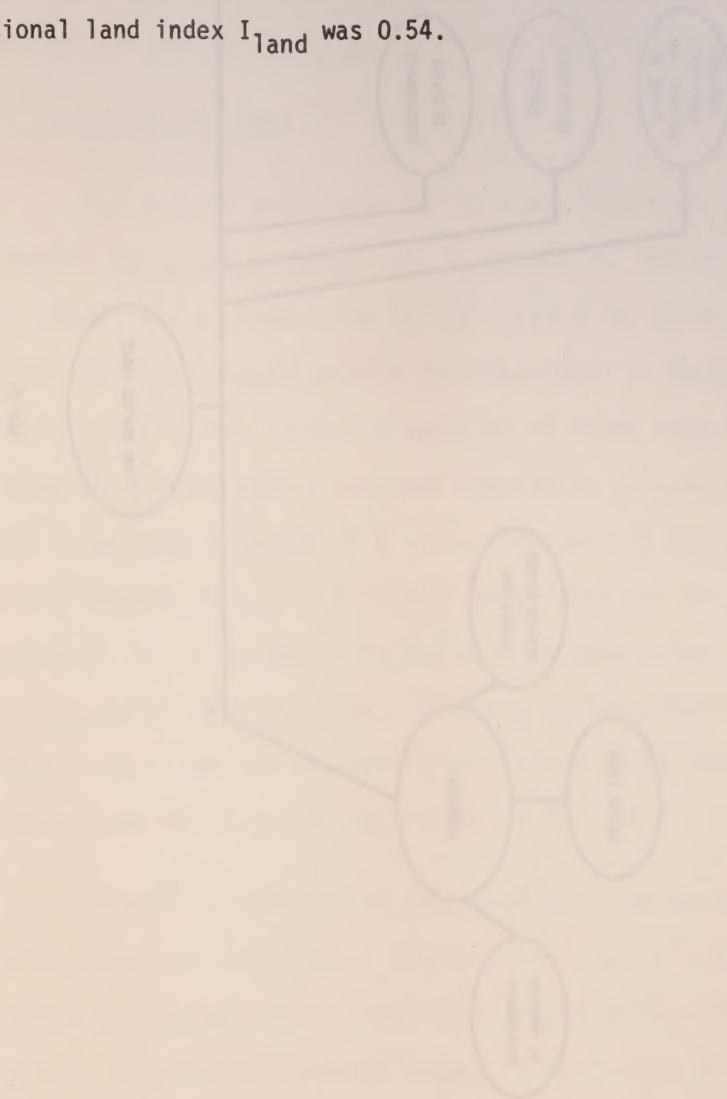
In Fig. L8, the index of accessibility to national and provincial parks is shown. Naturally, the lowest value of this index is in those regions of British Columbia, Alberta and Saskatchewan where the largest national parks are. The rest of western Canada also has relatively low values of I_{acc} . Moderate values are seen in the Maritimes, eastern Quebec and extreme western Ontario. The regions with the highest values are southern Ontario and southern Quebec. The average value of I_{acc} was 0.418, when only computed values falling on Canadian land were considered. Because population from the United States also has access to Canadian parkland, American population from states part or all of whose areas fall within 400 miles of the border were included in the calculations. Due to the nature of the following two maps, U.S. populations were not considered in their calculation.

In Fig. L9, the index of strip mining I_{sm} is shown. The areas of high values of the index are highly localized to Alberta, Saskatchewan and New Brunswick. Southern Ontario and Quebec have very low values of the index, indicating their great distances from the areas of strip mining. Other regions of the country have moderate values of the index. The overall national average is 0.52.

Fig. L10, shows the index of sedimentation I_{sed} . Although the measurements for this index were taken in rivers, they indicate the degree of washing-away of land. We see that high values of the index are again localized in the western Canada sedimentary basin, primarily in Alberta. The eastern half of Canada has very low values of I_{sed} , and these increase gradually until the far western Prairies are reached. Because of the proximity of British Columbia to the regions of high sediment-carrying rivers, I_{sed} is

also relatively high there. The average national value of I_{sed} is 0.62.

The six sub-indices were then combined into one national land quality index I_{land} using the standard root-mean-square system and a technique of consultation among experts called "Double Delphi". This technique combines the advantages of independent judgement and consensus. The national land index I_{land} was 0.54.



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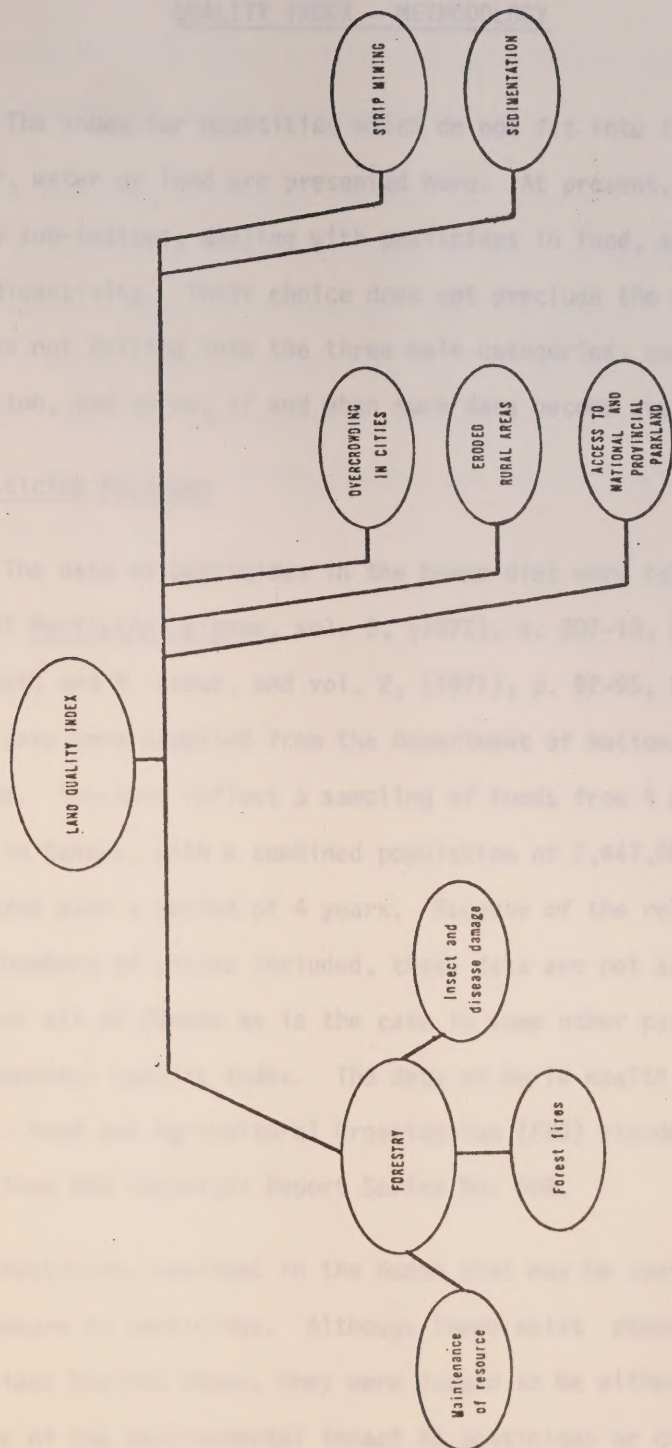
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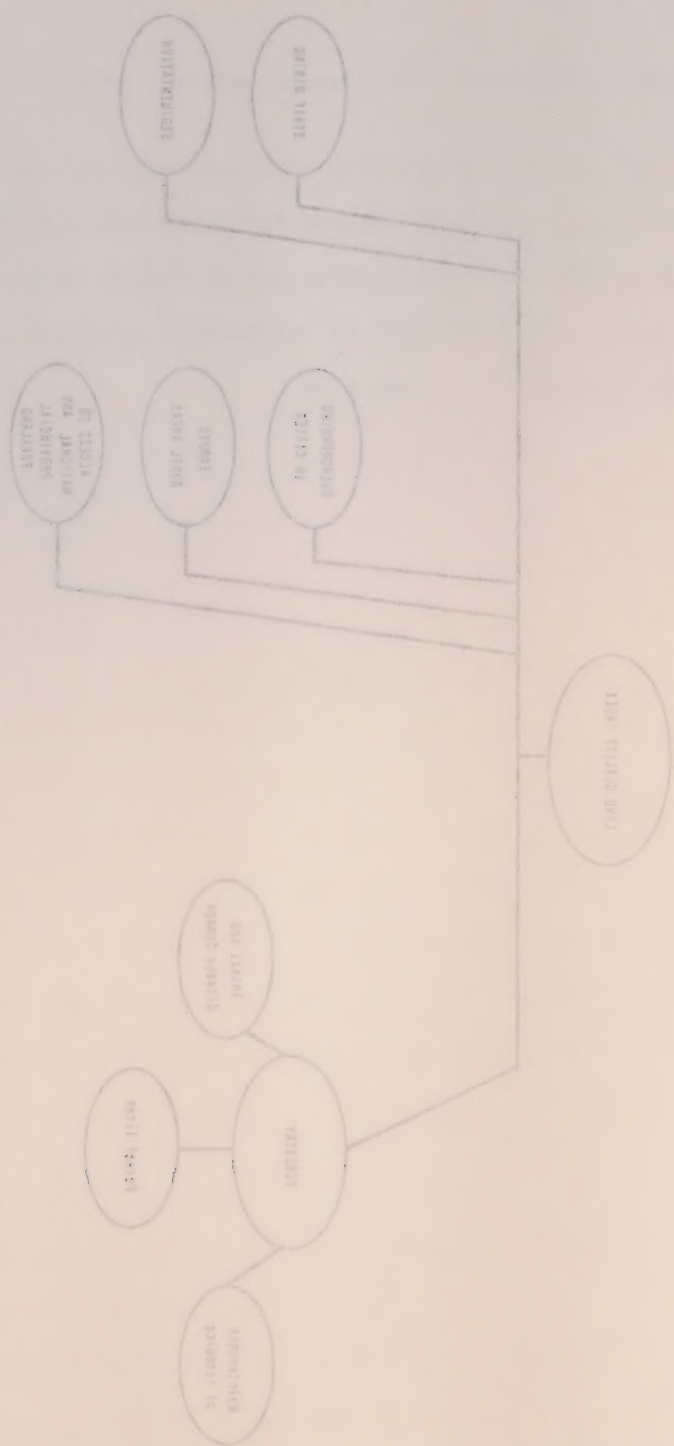
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technique combines the advantages of independent judgement and consensus.

The national land index I_{land} was 0.54.

FIG. 11





10/1/71

MISCELLANEOUS ENVIRONMENTAL

QUALITY INDEX - METHODOLOGY

The index for quantities which do not fit into the categories of air, water or land are presented here. At present, they consist of two sub-indices, dealing with pesticides in food, and exposure to radioactivity. Their choice does not preclude the use of other indices not falling into the three main categories, such as noise pollution, and so on, if and when such data become available.

I. Pesticide Residues

The data on pesticides in the human diet were taken from the journal Pesticide Science, vol. 3, (1972), p. 207-10, by D.C. Smith, E. Sandi, and R. Leduc, and vol. 2, (1971), p. 92-95, by D.C. Smith. Other data were supplied from the Department of National Health and Welfare. The data reflect a sampling of foods from 4 metropolitan areas in Canada, with a combined population of 2,447,000, and were collected over a period of 4 years. Because of the relatively small numbers of cities included, these data are not as representative of all of Canada as is the case in some other parts of the Environmental Quality Index. The data on World Health Organization (WHO) - Food and Agricultural Organization (FAO) standards were taken from WHO Technical Report Series No. 502.

Pesticides residues in the human diet may be used as a measure of exposure to pesticides. Although there exist other data on pesticides besides these, they were judged to be either an inadequate measure of the environmental impact of pesticides or confined only to those situations where a pesticides problem had occurred. If the

The index for quantities which do not fit into the categories of air, water or land are presented here. At present, they consist of two sub-indices, dealing with pesticides in food and exposure to radioactivity. Their index does not preclude the use of other indices not falling into the three main categories, such as noise, pollution, and so on, if and when such data become available.

Pesticide Residues

The data on pesticides in the human diet were taken from the Journal of the Science of Food and Agriculture, vol. 3, (1972), p. 201-10, by D.C. Smith, and R. Lebed, and vol. 5, (1974), p. 92-98, by D.C. Smith. Other data were supplied from the Department of National Health and Welfare. The data related to sampling of food from a representative cross in Canada, with a combined population of 2,441,800, and were sufficient over a period of 5 years. Because of the relatively small number of data included, these data are not as representative of all of Canada as the data in some other parts of the International Quality Index. The data on World Health Organization (WHO) - Food and Agricultural Organization (FAO) standards were taken from WHO Technical Report Series No. 302.

For each pesticide in the human diet may be used as a measure of exposure to pesticides. Although there were some other data on pesticides present there, they were judged to be either an inadequate measure of the environment, or not of pesticides or combined with the situation where a pesticide, whether or not allowed in the

latter data had been used, a distorted value of the pesticides residue index I_{pest} would have resulted.

To determine pesticides residues in Canadian diets, the average weight of each of 12 different groups of foods consumed per day per person in Canada was estimated. Then the amounts of residues of each of 5 major types of pesticides for each of the groups were measured. The data were averaged for Ottawa - Hull, Vancouver, Winnipeg and Halifax, and the average results are shown in the following Table M1.

1	Meats	0.191	70	1			
11	Cereals	0.150	4	2			
19	Total fats	0.172	6	1			
9	Leafy vegetables	0.046	7	6	1		
17	Legumes	0.032	1				
113	Roots	0.039	8	1	2		
114	Garden Fruits	0.080	11	1			
14	Fruits	0.171	7	2			
8	Oils & Fats	0.027	6	1	1	2	1
16	Sugars	0.185	3	1			
101	Dietary	0.094					

latter data had been used, a distorted value of the pesticides

residue index ^{pest} would have resulted.

To determine pesticides residues in Canadian diets, the average

weight of each of 15 different groups of foods consumed per day

per person in Canada was estimated. Then the amounts of residues of

each of 5 major types of pesticides for each of the groups were

measured. The data were averaged for Ottawa - Hull, Vancouver,

Winnipeg and Halifax, and the average results are shown in the

following Table M.

TABLE M1

Food Group	Name	Amount Consumed per Day (Kilogram)	Amount of pesticide residue, in parts per billion				
			DDT	Aldrin/Dieldrin	Lindane	Malathion	Heptachlor
I	Dairy Products	0.496	5	1	1		
II	Meats	0.191	18	1	1		
III	Cereals	0.150	4		8	7	
IV	Potatoes	0.172	6	1			
V	Leafy Vegetables	0.040	7	6	1	4	1
VI	Legumes	0.032	1				
VII	Roots	0.039	8	1	4		
VIII	Garden Fruits	0.080	11	1			
IX	Fruits	0.171	7	2			
X	Oil & Fats	0.027	8	1	1	2	1
XI	Sugars	0.145	2	1			
XII	Drinks	0.694					

TABLE MI

Food Group	Name	Amount Consumed per Day (Kilogram)	Amount of pesticide residue in parts per billion				Hepta-chlor	
			DDT	Aldrin	Lindane	Melathion		
I	Dairy Products	0.496	2	1	1			
II	Meats	0.191	18	1	1			
III	Cereals	0.150	4		8	7		
IV	Potatoes	0.125	6	1				
V	Leafy Vegetables	0.040	7	6	1	4	1	
VI	Legumes	0.035	1					
VII	Roots	0.039	8	1	4			
VIII	Garden Fruits	0.080	11	1				
IX	Fruits	0.171	7	2				
X	Oil & Fats	0.027	8	1	1	2	1	
XI	Sugars	0.145	2	1				
XII	Drinks	0.694						

The table gives the amount of each of the listed pesticide residues in parts per billion for each major food group. For example, in the dairy products group there is an average of 5 parts per billion of DDT, whereas in the drinks group there is no detectable DDT. One kilogram equals about 2.2 pounds.

Now the actual amount of pesticides residues in the average diet was calculated. This was done by multiplying the weight consumed of each food group by the fraction of the pesticide residue found for that group, and then adding together the numbers found (for each group) to get a grand total for each pesticide. For example, for malathion we have

$$\begin{aligned} & \frac{7 \text{ parts}}{1 \text{ billion parts}} \times 0.150 \text{ kilogram} \\ & + \frac{4 \text{ parts}}{1 \text{ billion parts}} \times 0.040 \text{ kilogram} + \frac{2 \text{ parts}}{1 \text{ billion parts}} \times 0.027 \text{ kilogram (M1)} \end{aligned}$$

In other words, for each pesticide we multiply the quantity in the third column by the quantity in the "amount of pesticide" column, and add up all the products. The term $\frac{\text{parts}}{\text{billion parts}}$ expresses the fact that the pesticide residues are in parts per billion. The "parts" cancel in the first section of the fractions of equation (M1), so that we have for malathion

$$\begin{aligned} & 7 \times 0.150 \frac{\text{kilogram}}{\text{billion}} + 4 \times 0.040 \frac{\text{kilogram}}{\text{billion}} \\ & + 2 \times 0.027 \frac{\text{kilogram}}{\text{billion}} \end{aligned} \quad \text{(M2)}$$

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Now the actual amount of pesticides residues in the average diet was calculated. This was done by multiplying the weight consumed of each food group by the fraction of the pesticide residue found for that group, and then adding together the numbers found (for each group) to get a grand total for each pesticide. For example, for malathion we have

$$\frac{7 \text{ parts}}{1 \text{ billion parts}} \times 0.150 \text{ kilogram}$$

$$+ \frac{4 \text{ parts}}{1 \text{ billion parts}} \times 0.040 \text{ kilogram} + \frac{2 \text{ parts}}{1 \text{ billion parts}} \times 0.027 \text{ kilogram (M)}$$

In other words, for each pesticide we multiply the quantity in the third column by the quantity in the "amount of pesticide" column, and add up all the products. The term $\frac{\text{parts}}{\text{billion parts}}$ expresses the fact that the pesticide residues are in parts per billion. The "parts" cancel in the first section of the fractions of equation (M), so that we have for malathion

$$\frac{7 \times 0.150 \text{ kilogram}}{\text{billion}} + \frac{4 \times 0.040 \text{ kilogram}}{\text{billion}}$$

$$+ \frac{2 \times 0.027 \text{ kilogram}}{\text{billion}}$$

(M)

One billionth of a kilogram is a microgram (one millionth of a gram), so that equation (M2) becomes

$$\begin{aligned}
 & 7 \times 0.150 \text{ microgram} + 4 \times 0.040 \text{ microgram} \\
 & + 2 \times 0.027 \text{ microgram} \\
 & = 1.050 + 0.160 + 0.054 \text{ micrograms} \quad (M3) \\
 & = 1.3 \text{ micrograms}
 \end{aligned}$$

By this method, the amount of residues of each pesticide in the average diet was found, and results are shown in Table M2, along with the WHO - FAO acceptable daily intake (assuming a 70 kilogram body weight, about 154 pounds). The results in Table M2 may differ slightly from those calculated by the procedure in equation (M1), (M2) and (M3), since the amounts of pesticides shown in Table M1 were rounded off to the nearest part per billion, and Table M2 was computed exactly.

TABLE M2

	Pesticide				
	DDT	Aldrin/Dieldrin	Lindane	Malathion	Heptachlor
Daily Intake (in microgram)	10.5	1.9	1.6	1.5	0.14
WHO - FAO Acceptable daily Intake (microgram)	350	7	875	1400	35
Intake as a per- centage of WHO - FAO Acceptable Intake	3.0	27.5	0.18	0.11	0.41

One billionth of a kilogram is a microgram (one millionth of a gram), so that equation (M2) becomes

$$\begin{aligned} & 7 \times 0.150 \text{ microgram} + 4 \times 0.040 \text{ microgram} \\ & + 2 \times 0.027 \text{ microgram} \\ & = 1.050 + 0.160 + 0.054 \text{ micrograms} \\ & = 1.3 \text{ micrograms} \end{aligned} \quad (M3)$$

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TABLE M2

Pesticide	DDT	Aldrin/Dieldrin	Lindane	Malathion	Heptachlor
FAO acceptable intake percentage of WHO - intake as a per-	3.0	27.5	0.18	0.11	0.41
WHO - FAO Acceptable daily intake (microgram)	350	7	875	1400	35
Daily intake (in microgram)	10.5	1.9	1.5	1.5	0.74

The same results are shown in Fig. M1. We see that the Canadian levels are considerably below the levels deemed to be acceptable by an international committee of experts. Using the root-mean-square technique, the following equation was used to determine I_{pest} , the index of pesticides residues:

$$I_{\text{pest}} = \sqrt{\frac{I_1^2 + I_2^2 + I_3^2 + I_4^2 + I_5^2}{5}} \quad (\text{M4})$$

where I_1 is the index for DDT, and is $I_1 = 0.03$. Similarly, $I_2 = 0.275$, $I_3 = 0.018$, and so on. As usual, the denominator is the sum of the weights, which are all equal in this equation.

When these indices are substituted into equation (M4), we find $I_{\text{pest}} = 0.124$.

II Radioactivity

The data for this section were taken from "Radiation Surveillance in Canada", nos. RPD - 102, 103 and 104 (1971), published by the Department of National Health and Welfare. The data generally had the units (level of radioactivity)/(volume of air or weight of substance containing the radioactivity). For example, the levels of the isotope strontium - 90 in milk is given in picocuries per gram of calcium in milk. "Pico" means a millionth of a millionth, and "Curie" is a unit of radioactivity.

However, we would like to convert these units into millirems, which show the effect of radioactivity on humans. For this purpose, a set of "conversion factors" was supplied by the Department of National

The same results are shown in Fig. M1. We see that the Canadian levels are considerably below the levels deemed to be acceptable by an international committee of experts. Using the root-mean-square technique, the following equation was used to determine I_{pest} , the index of pesticides residues:

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where I_1 is the index for DDT, and its $I_1 = 0.03$. Similarly, $I_2 = 0.25$, $I_3 = 0.08$, and so on. As usual, the denominator is the sum of the weights, which are all equal in this equation.

When these indices are substituted into equation (M4), we find

$$I_{\text{pest}} = 0.124$$

11 Radioactivity

The data for this section were taken from "Radiation Surveillance in Canada", nos. R20 - 102, 103 and 104 (1971), published by the Department of National Health and Welfare. The data generally had the units (level of radioactivity)/(volume of air or weight of substance containing the radioactivity). For example, the levels of the isotopes strontium - 90 in milk is given in picocuries per gram of calcium in milk. "pico" means a millionth of a millionth, and "Curie" is a unit of radioactivity.

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Health and Welfare, and is shown in Table M3:

TABLE M3

<u>Source of Radioactivity</u>	<u>Original Units</u>	<u>Conversion Factor (into millirems)</u>
Total beta radioactivity in air*	Picocuries per cubic meter	0.39
Strontium - 90 in milk	Picocuries per gram of calcium	0.14
Cesium - 137 in milk	Picocuries per gram of potassium	0.05
Strontium - 90 in water	Picocuries per liter	0.26
Cesium - 137 in water	Picocuries per liter	0.025

* Beta radioactivity is a type of radioactivity, and refers to what is known technically as "old fission products", that is, sources of radioactivity from fallout which have been in the air for a relatively long time.

As an example of how this table was used, if we had 0.1 picocuries per cubic meter of total beta radioactivity in air, we would then have

$$0.1 \times 0.39 = 0.039 \text{ millirem per year, equivalent whole-body dose}$$

The "rem" is a unit measuring the effect of radioactivity on humans, and "milli" is one thousandth. "Whole-body dose" means that the entire body receives that dose of radioactivity, rather than a specific organ. In

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Total beta radioactivity in air*	Picocuries per cubic meter	0.39
Strontium - 90 in milk	Picocuries per gram of calcium	0.14
Cesium - 137 in milk	Picocuries per gram of potassium	0.02
Strontium - 90 in water	Picocuries per liter	0.26
Cesium - 137 in water	Picocuries per liter	0.025

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this section, we will add the contributions to the overall human exposure from three sources: radioactivity in air, radioactivity in whole milk, and radioactivity in surface waters near nuclear power reactors. We then compare these to the total background radiation level, which is taken as 100 millirem per year. The background radiation level is what would occur if there were no human activities.

a) Radioactivity in air: The data were taken from RPD 102, 103 and 104 and converted to millirems by the conversion factor of Table M3. For graphical purposes only, it was decided to compare the radioactivity dose-rate in air with an air "background" (or natural) radiation level. This level is taken to be 1.3 millirem per year, and represents the dose from breathing of alpha-radioactivity in air. Then the index of radioactivity in air is

$$I_{\text{dose a}} = \frac{C_{\text{dose a}}}{S_{\text{dose a}}} \quad (\text{M5})$$

where $C_{\text{dose a}}$ is the average radiation level for a city for 1971, and $S_{\text{dose a}}$ is the background level (1.3 millirem per year). Indices were calculated for 24 locations with a combined metropolitan population of 9,875,000. To determine a national average, the weighting system of Table I1 was used, and the national index was Results for each station are shown in Fig. M2.

Because data were available on a time basis, the index $I_{\text{dose a}}$ was also computed as it varied through 1971. Results are shown in Fig.

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$$(M2) \quad \frac{\text{dose } a^1}{\text{dose } a^2} = \frac{\text{dose } a^1}{1.3}$$

where $\text{dose } a^1$ is the average radiation level for a city for 1971, and $\text{dose } a^2$ is the background level (1.3 millirem per year). Indices were calculated for 24 locations with a combined metropolitan population of 9,875,000. To determine a national average, the weighting system of Table 11 was used, and the national index was Results for each station are shown in Fig. M2.

Because data were available on a time basis, the index $\text{dose } a^1$ was also computed as it varied through 1971. Results are shown in Fig.

M3.

It should be noted again that this computation was done only to illustrate the variation in space and time of the radioactivity effects from the air. These will be combined with the effects from the two other radioactivity categories to produce an overall radioactivity index.

b) Radioactivity in whole milk: Again, the actual levels of radioactivity in milk were multiplied by the conversion factors of Table M3 in order to measure their effects on humans. Both strontium -90 and cesium - 137 were measured. As an example, one location had an average radioactivity level of 6 picocuries per gram of calcium in milk for 1971. Using Table M3, this corresponds to 0.84 millirems per year.

A similar calculation was made for the isotope cesium - 137.

Measurements were made at 16 Canadian cities with a combined metropolitan population of 9,860,000. Using the weighting system of Table II, the national average was 1.01 millirems per year. It was not possible to have a separate value of this index for this quantity, since the normal levels of radioactivity in milk are essentially zero. However, as mentioned before, this national average will be added to those of the other two sub-indices to produce an overall value, which will then be compared to the 100 millirems per year background from all sources.

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c) Radioactivity in waters near nuclear power reactors: For 1971, 16 sampling stations were monitored, near 5 nuclear reactors. Since neither the exact population near each nuclear reactor nor the flow rates of the adjacent rivers or lakes were known, it was decided to give each monitoring station equal weight in the compilation of a total national average of radioactivity near nuclear reactors. Most of the radioactivity near reactors comes from natural background levels and nuclear fallout.

The 16 stations were in groups (on the Ottawa River, Lake Huron, Lake Ontario, St. Lawrence River and Winnipeg River) and three radioisotopes (strontium - 89, strontium - 90, and cesium-137) were monitored at each. The contribution of strontium - 89 was very close to zero, so this radioisotope was disregarded in the calculations. Again, the conversion factors of Table M3 were used to convert the original units of measurement to millirems per year.

We now have to take account of the fact that at present, comparatively few of the population is in the vicinity of a nuclear reactor. This means that we will give a lower relative weight to this sub-index than the other two sub-indices on radioactivity in air and milk. These last two are assumed to have the same weight, since the entire population is exposed to any radioactivity in the air, and almost the entire population drinks milk or consumes milk products.

Ideally, the "vicinity" of a nuclear reactor should mean the farthest distance at which no radiation is detected. For purposes of this index, "vicinity of a nuclear reactor" was defined as being within

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Ideally, the "vicinity" of a nuclear reactor should mean the farthest distance at which no radiation is detected. For purposes of this index, "vicinity of a nuclear reactor" was defined as being within

a radius of 28 miles of any of the 5 nuclear reactors discussed above. This distance is the highest for which calculations concerning nearby populations were made in "Pickering Generating Station - Safety Report", Atomic Energy of Canada, 1968, vol.1, p. 2:5. For purposes of simplicity, the population of those counties or census districts, part of which fell within 28 miles of these reactors, were added together to give the total population in their vicinity. Then the weight for radioactivity for waters near nuclear reactors was

$$W_{nr} = \frac{P_1 + P_2 + P_3 + \dots}{P_T} \quad (M6)$$

where $P_1, P_2, P_3, \dots$ are the populations of each of these counties, and P_T is the total population of Canada. We find that $W_{nr} = 0.16$. Then the total index for radioactivity is

$$I_{rad} = \frac{C_{dose\ a} + C_{wm} + 0.16 C_{nuc\ rea}}{S_{rad}} \quad (M7)$$

where $C_{dose\ a}$ is the radioactivity dose-rate (effect on humans) from the air, C_{wm} is the dose-rate from whole milk, $C_{nuc\ rea}$ is the dose-rate from waters in the vicinity of nuclear reactors, and S_{rad} is the background dose-rate, which equals 100 millirems per year.

In equation (M7), the usual root-mean-square way of combining indices was not used because the C's are quantities of dose-rate, not indices in themselves. This means that we are combining similar

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$$I_{rad} = \frac{C_{dose a} + C_{wm} + 0.16 C_{nuc rad}}{2} \quad (M7)$$

where $C_{dose a}$ is the radioactivity dose-rate (effect on humans) from the air, C_{wm} is the dose-rate from whole milk, $C_{nuc rad}$ is the dose-rate from waters in the vicinity of nuclear reactors, and 2 is the background dose-rate, which equals 100 millirems per year.

In equation (M7), the usual root-mean-square way of combining indices was not used because the C 's are quantities of dose-rate, not indices in themselves. This means that we are combining similar

quantities, and not unitless indices. It should also be noted that as more nuclear reactors are built, the weight W_{nr} of 0.16 used in this equation will increase.

Using the data from parts (a), (b) and (c) of this section, we have

$$\begin{aligned} I_{rad} &= \frac{0.066 + 1.01 + 0.16 (0.27)}{100} \\ &= 0.011 \end{aligned} \quad (M8)$$

III Combined Miscellaneous Environmental Index

In order to calculate an overall Environmental Quality Index for Canada, the various individual indices have to be combined together. The sub-indices on radioactivity and pesticides residues are now combined together as a "Miscellaneous Environmental Quality Index". It should be noted that the prime significance of this is only as a method for the combination of the individual indices.

Since there was no simple way to judge the relative importance of the pesticides residue and radioactivity indices I_{pest} and I_{rad} , it was felt that equal weights would be assigned to each until conclusive evidence showed otherwise. Then using the root-mean-square technique,

$$\begin{aligned} I_{misc} &= \sqrt{\frac{I_{pest}^2 + I_{rad}^2}{2}} \\ &= \sqrt{\frac{(.124)^2 + (0.011)^2}{2}} \\ &= 0.088 \end{aligned} \quad (M9)$$

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$$(M9) \quad I_{misc} = \sqrt{\frac{I_{pest}^2 + I_{rad}^2}{2}} = \sqrt{\frac{(1.24)^2 + (0.011)^2}{2}} = 0.88$$

INTERPRETATION

As mentioned above, the miscellaneous environmental quality index I_{misc} , as written in equation (M9), can be modified to take account of other quantities like odor and noise levels when those data become available on a national basis. This would be done by rewriting equation (M9) as follows:

$$I_{\text{misc}} = \sqrt{\frac{I_{\text{pest}}^2 + I_{\text{rad}}^2 + aI_1^2 + bI_2^2 + \dots}{2 + a + b}} \quad (\text{M10})$$

Here $I_1, I_2, \dots$ are the indices for other new miscellaneous pollutants, and $a, b, \dots$ are the weights allotted for each particular index. The number 2 in the denominator of equation (M10) is the sum of the weights of the indices I_{pest} and I_{rad} .

Now to discuss the indices already found. In Fig. M1, we see that aldrin/dieldrin pesticide residues have the highest concentration in a typical Canadian diet, as a percentage of the WHO - FAO acceptable daily intakes, followed by the DDT groups, and then heptachlor. However, it should be noted that even the aldrin/dieldrin residues are only about 27% of the acceptable levels. This means that the level of pesticide residues in the typical Canadian diet is very low. This is borne out by the fact that I_{pest} , the index of pesticides in diet, which is an average of these 5 types of pesticides, is 0.124, close to the "perfect" value of 0 which would be achieved if there were no pesticide residues at all in the Canadian diet. The calculations for this are shown in equation (M4).

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No geographical depiction of the pesticides data was possible in view of the limited number of sites from which it was gathered. It should be noted that the typical diet shown in Table M1 may differ from those of some people. For example, those who eat less dairy products (Group I) and fruits (Group IX) than the average will consume less malathion residues than the average person.

The index for the dose-rate of radioactivity in the air $I_{\text{dose a}}$ is shown in Fig. M2. The indices range from a high of around 0.07 to a low of about 0.03. As discussed in the Methodology, the calculations of this sub-index was used only to illustrate the air dose-rate to the air "background" (or natural dose-rate).

In Fig. M2, we see that most of eastern and western Canada have similar values of $I_{\text{dose a}}$. Low readings occur on the West Coast and in far northern Canada.

In Fig. M3, we present the same data in terms of time. We see that the levels of the first quarter of 1971 increase sharply in the second quarter, but decrease rapidly as the year draws to a close.

The levels of radioactivity dose-rate in whole milk and in the vicinity of nuclear reactors were also calculated. However, no indices were computed for these two components of the total radioactivity dose-rate, because no standards or comparable background levels exist. However, it can be seen from equation (M8) that any such indices for these two components would be very low. We see that if we compared each to the total background dose-rate (100 millirems per year), the indices

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However, it can be seen from equation (10) that any such indices for these

two components would be very low. We see that if we compared each to

the total background dose-rate (100 millirems per year), the indices

for whole milk and waters near nuclear reactors would be 0.01 and 0.0004, which are very low.

For these reasons, the total index of radioactivity is also very low, at 0.011, in spite of the fact that the national index for radioactivity in air is higher at 0.05. In the latter case, we are using a background dose-rate of 1.3 millirems per year, and in the former, the background dose-rate is 100 millirems per year.

Finally, the total miscellaneous environmental quality index I_{misc} was calculated. Equal weights were assigned to the index of pesticide residues I_{pest} and the index of radioactivity I_{rad} . Because of the relatively higher level of the latter, the total index I_{misc} had the value of 0.088. No geographical distribution could be shown because it was not available for some of the data used.

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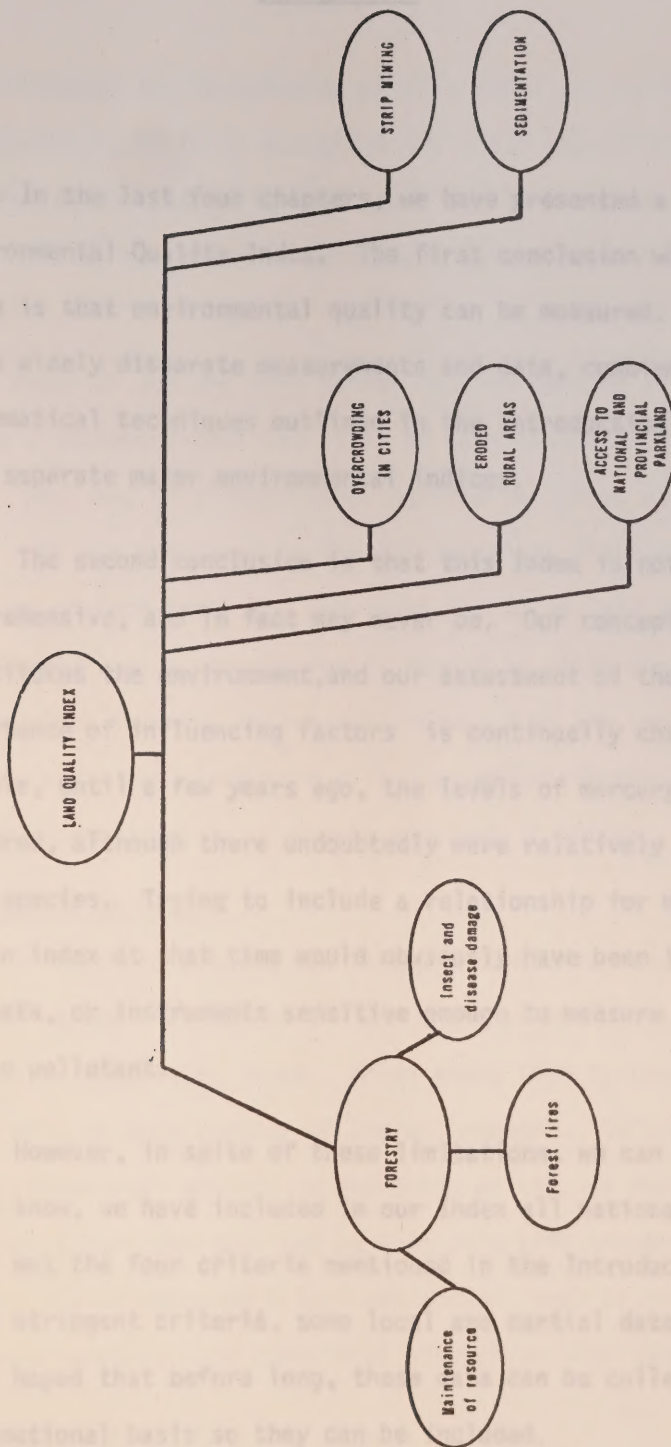
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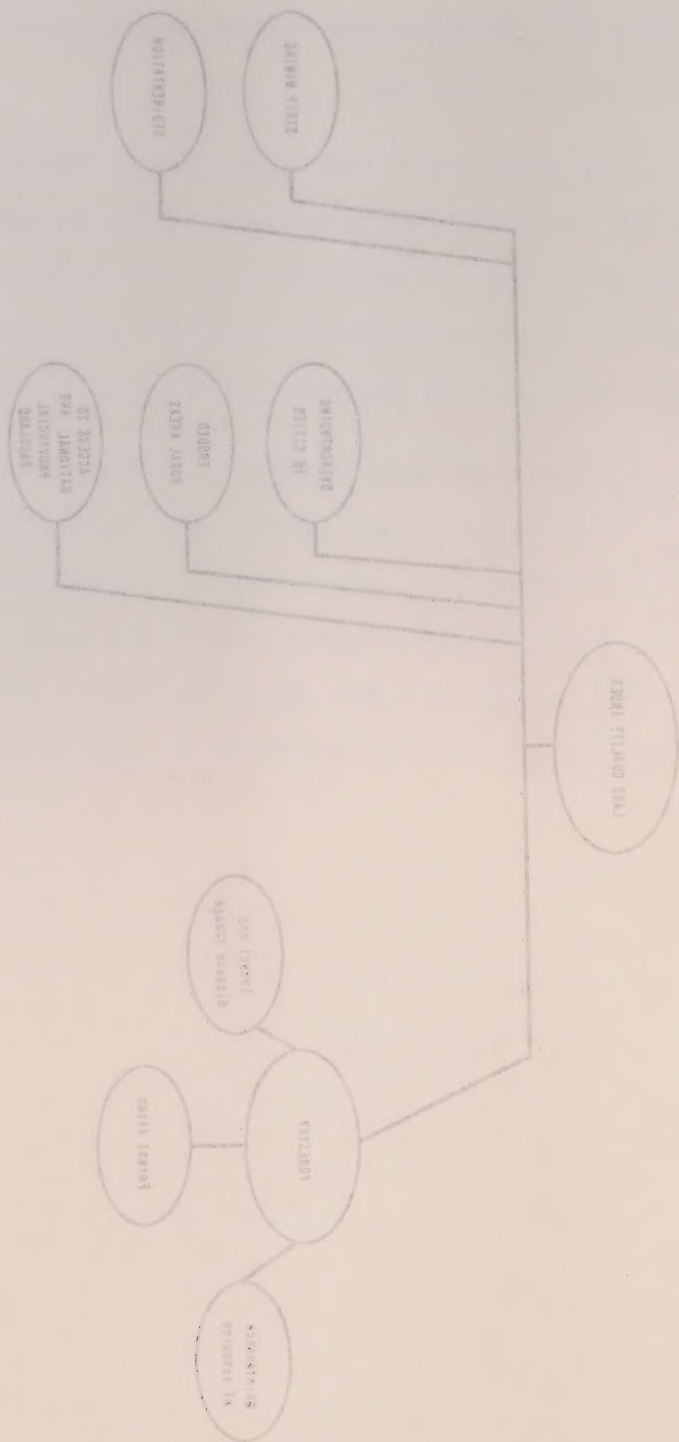
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FIG. LI





CONCLUSIONS

In the last four chapters, we have presented a National Environmental Quality Index. The first conclusion which can be drawn is that environmental quality can be measured. We have taken widely disparate measurements and data, combined them with the mathematical techniques outlined in the Introduction, and calculated four separate major environmental indices.

The second conclusion is that this Index is not absolutely comprehensive, and in fact may never be. Our concept of what constitutes the environment, and our assessment of the relative importance of influencing factors is continually changing. For example, until a few years ago, the levels of mercury in fish were not measured, although there undoubtedly were relatively high levels in some species. Trying to include a relationship for mercury in fish for an index at that time would obviously have been impossible without any data, or instruments sensitive enough to measure small quantities of the pollutant.

However, in spite of these limitations, we can say that as far as we know, we have included in our Index all nationally available data which met the four criteria mentioned in the Introduction. Because of these stringent criteria, some local and partial data were not included. It is hoped that before long, these data can be collected and evaluated on a national basis so they can be included.

CONCLUSIONS

In the last four chapters, we have presented a National Environmental Quality Index. The first conclusion which can be drawn is that environmental quality can be measured. We have taken widely disparate measurements and data, combined them with the mathematical techniques outlined in the Introduction, and calculated four separate major environmental indices.

The second conclusion is that this index is not absolutely comprehensive, and in fact may never be. Our concept of what constitutes the environment, and our assessment of the relative importance of influencing factors, is constantly changing. For example, until a few years ago, the levels of mercury in fish were not measured, although there undoubtedly were relatively high levels in some species. Trying to include a relationship for mercury in fish for an index at that time would obviously have been impossible at that time, or instruments sensitive enough to measure small quantities of the pollutant.

However, in spite of these limitations, we can say that as far as we know, we have included in our index all reasonably available data which met the four criteria mentioned in the Introduction. Because of these stringent criteria, some local and partial data were not included. It is hoped that before long, these data can be collected and evaluated on a national basis so they can be included.

Although the formulation of this Index was mainly by Federal personnel, we fully recognize and would appreciate assistance from experts at the provincial and local level. We intend to utilize this expertise as the Index is continued, expanded and made more comprehensive.

Those of you who have turned to this section in the expectation of finding a statement that the state of the Canadian environment is "good" or "bad" may be disappointed, because we cannot make either statement. As was mentioned in the Introduction, the exact interpretation of the value of each index and sub-index has to be left to the individual reader. However, as a consolation it should be noted that it will be possible to draw more definitive conclusions from the next edition of this Index, since each component will then either decrease ("improve"), increase ("become worse"), or remain constant in value.

What Remains to be Done

As has been pointed out in the Introduction and the rest of the EQI, we have not solved all the problems connected with devising an environmental index. Prime among them is the paucity of enough data on many aspects of the environment. Before we can tell whether environmental quality is improving or not, we have to know its present state, and this can be done only with enough reliable data. Some fields where more data are needed, such as noise pollution, odours, solid wastes, some industrial discharges into waterways, and

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so on, have already been mentioned in the text. A complete list would fill pages. We feel that the specification of these areas is something in which readers of this booklet should participate.

Secondly, we need to know more about the effect of various pollutants on human health and well-being. This knowledge is important, since without it we cannot relate the levels of pollutants to estimates of environmental quality. Although much work has been done in the field of toxicology in the past, we need to expand these efforts to take greater account of the many new potential pollutants being generated each year.

Thirdly, we have to continuously develop better methods of evaluating the relationships between different aspects of environmental quality, so that we can put them on a firmer mathematical base. The Introduction mentioned several ways in which the aspects were related, but this was by no means an exhaustive list. The weights which were assigned to different environmental quantities were produced on the basis of expert judgement. However, the public has both a right and a duty to formulate its opinion on which parts of the environment are more important than others. These opinions, along with those of experts, will be taken account of in future editions of the EQI.

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Local, Regional and National Environmental

Indices

It would be desirable to combine environmental indices on air, water and land so that a total EQI could be computed for localities and regions. Unfortunately, the data available do not permit this at present. This is the reason that maps of the total air, water, land or miscellaneous indices were not presented. In each case, either some data referred only to national measurements or was partially incomplete on a geographical basis. As a result, any attempt at depiction of total air, water, land or miscellaneous indices on a local or regional basis would be inaccurate because of these deficiencies. We are aware both of these problems and of the need for broad local and regional environmental indices. Formulating them will be one of the goals we set ourselves in subsequent editions of the EQI.

Because some local data were missing, we generally could not construct broad local environmental indices. However, since each of the four major indices was itself combined into a national average index, we can make an attempt to calculate a combined national environmental quality index taking account of these four indices. The next and final section shows our reasoning.

A Combined National Environmental Quality Index

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To determine weights for them, it was first noted that the miscellaneous index was much less comprehensive in coverage than the other three indices, indicating that it should receive a lower weight.

Furthermore, because air, water and land are all recognized as major components of environmental quality, and since no data were available to assess the relative importance of each, it was decided to weight them equally.

Based on these assumptions, if total environmental quality is given a total weight of 1, then the weights assigned to the air, water, land and miscellaneous indices were 0.3, 0.3, 0.3, and 0.1, respectively. It should be noted that slight changes in these weights will change the value of the combined National Environmental Quality Index only slightly. For example, if the weight for the water index had been 0.25 instead of 0.3, there would have been almost no change in the combined Environmental Quality Index.

The values of I_{air} , I_{water} , I_{land} , and I_{misc} were 0.99, 0.73, 0.54 and 0.088 respectively.

Using the root-mean-square technique which has been used to combine different sub-indices, we then have

$$I_{\text{EQI}} = \sqrt{\frac{0.3 (I_{\text{air}})^2 + 0.3(I_{\text{water}})^2 + 0.3(I_{\text{land}})^2 + 0.1(I_{\text{misc}})^2}{1}} \quad (C1)$$

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$$\begin{aligned} I_{EQI} &= \sqrt{0.3(0.99)^2 + 0.3(0.73)^2 + 0.3(0.54)^2 + 0.1(0.088)^2} \\ &= 0.74 \end{aligned}$$

Results are shown in Fig. C1. Each of the four components of the combined Environmental Quality Index is outlined vertically. This is done to give a graphical depiction of their relative weights. The height of each outline corresponds to the fractional weight of the particular index. Thus, the first three indices are outlined up to 0.3 and the Miscellaneous index extends to 0.1. We will next discuss the initial four coloured bars, starting from the left. Each of the four main indices of the EQI are shown as a coloured bar. The length of each of the bars is proportional to the fraction of the combined Environmental Quality Index that each of the four indices comprises. To calculate the length, the weight of the index is multiplied by the actual value of the index. For example, the air index is coloured up to $0.3 \times 0.99 = 0.297$, and so on.

Of the three major indices, the land index has the lowest ("best") value and the air has the highest ("worst") value.

The right-hand side of Fig. C1 shows the combined index $I_{EQI} = 0.74$. The column is outlined to $I_{EQI} = 1$, the sum of the weights of each of its four components. In theory, at least, the value of I_{EQI} (or any of its components) could be greater than 1.

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What does I_{EQI} mean?

The question now arises: what does the value for I_{EQI} , the combined environmental quality index, mean? As was pointed out in the Introduction, the farther we get mathematically from our original data, the more nebulous the interpretation of the resultant index. Since I_{EQI} is based on the combination of all the data we have considered in the previous pages, one way of naming it would be to call it the most nebulous index of all.

However, a more accurate way of deciding what it means is to define it as "the number resulting from all the physical and mathematical assumptions in all the preceding sections and subsections". In other words, the value of $I_{EQI} = 0.74$ is not the measure of the state of the Canadian environment, but rather a measure, based on the many assumptions we have had to make.

An analogy to what this number means can be drawn to two other numbers familiar to the public, the Intelligence Quotient (IQ) and the Gross National Product (GNP). The intelligence of a person can never be perfectly measured, since there is wide disagreement as to what it constitutes. However, the standardized IQ test is a measure of certain forms of intelligence, and so can prove valuable when used carefully.

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So in analogy to IQ and GNP, the index I_{EQI} is a mathematical attempt to describe the total environment, rather than the index for the total environment.

Of course, the IQ and GNP have certain advantages over I_{EQI} , since the former two deal in uniform quantities (standardized answers to tests and the dollar, respectively), and any index based on environmental data is of necessity founded on widely disparate quantities. However, since the responsible agency for "A National Environmental Quality Index for Canada" is Environment Canada, and this, as the name implies, includes air, water and land, we feel that an attempt should be made to at least approximate the total environments in which Canadians live.

Many data and structural qualifications have been expressed in this booklet, but we believe that it is better to take a first step rather than not make a move because of the difficulties. We feel we have a responsibility to interpret the data on the environment to the Canadian people, and to create a method of measuring the success of environmental management programs. Environment Canada would welcome comments and suggestions for improvement.

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LIST OF TITLES, LEGENDS, CAPTIONS,

"INSIDE CAPTIONS"

- A1. Title: Schematic Diagram of Air Quality Index.
- A2. Title: Suspended Particulate Matter Index I_{SPM} .
Caption: Highest regions of the index are in southern Ontario, with high regions also in Quebec, Alberta and British Columbia. Cities in the Maritimes generally have low values.
Inside Caption: Coloured circles around a city indicate only the average range of values for that city, and do not necessarily mean that the entire coloured areas have that value of the index.
- A3. Title: Sulphur Dioxide Index I_{SO_2} .
Caption: Most of eastern Canada has relatively high values of the index, as compared to those in western Canada. The scale for this map is different from that for the preceding one.
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- A4. Title: Index of Suspended Particulate Matter, I_{SPM} , on a Month-to-Month Basis.
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A5. Title: Index of Sulphur Dioxide, I_{SO_2} , on a Month-to-Month Basis.

Caption: We see large variations in this index, with the maximums occurring in the winter months. At those times, the index is relatively high, with a value of greater than 2.0. It decreases to about 0.8 by July.

A6. Title: Index of Coefficient of Haze, I_{COH} , on a Month-to-Month Basis.

Caption: There is a significant variation in the values of this index, but it is not as great as in the preceding diagram. The index reaches a value of about 1.4 in the winter months, and decreases to about half this value in the summer months.

A7. Title: Index of Inter-Urban Air Quality, I_{reg} .

Legend: ————— Contour of equal index

• Sampling Station

Caption: Southwestern Ontario has the highest values of this index. Values decrease towards the north. The southern parts of British Columbia, Alberta and Saskatchewan have relatively low values of the index, as does western Alberta.

Inside : Sampling stations within a given shade lie within that range
Caption of values of the index. This arrangement does not imply that all areas in a particular shade have the same range of values.

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Index of Coefficient of Haze, COH , on a Month-to-Month Basis.

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AB.

There is a significant variation in the values of this index, but it is not as great as in the preceding diagram. The index reaches a value of about 1.4 in the winter months, and decreases to about half this value in the summer months.

Caption:

Index of Inter-Urban Air Quality, I_{reg} .

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Sampling stations within a given shade lie within that range of values of the index. This arrangement does not imply that all areas in a particular shade have the same range of values.

Inside :
Caption

A8. Title: Index of Industrial Emissions of Sulphur Dioxide, $I_{ie}(SO_2)$, Averaged Provincially.

Caption: The Prairie Provinces and Ontario have relatively high values of the index, and the Maritime Provinces have relatively low values.

A9. Title: Index of Industrial Emission of Suspended Particulate Matter, $I_{ie}(SPM)$, Averaged Provincially.

Caption: This map differs considerably from the preceding one. Newfoundland, Nova Scotia, Alberta and Saskatchewan now have the highest values of this index.

W1. Title: Schematic Diagram of Water Quality Index

W2. Title: Index of Normalized Unit Load for Municipal Waste Treatment Plants, Averaged Provincially, I_{nul} .

Caption: Ontario, Manitoba and Alberta have the lowest values of this index. The "unit load" index generally indicates pollution clean-up efforts.

W3. Title: Index of Total Load for Municipalities, Averaged Provincially, I_{ℓ} .

Caption: Ontario and Quebec have the highest values of this index. The "total load" index is a measure of the total quantity of waste constituents discharged.

AB.

Title:

Index of Industrial Emissions of Sulphur Dioxide, 10^6 (20 $^{\circ}$ S).

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Caption:

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Title:

Index of Industrial Emission of Suspended Particulate Matter, 10^6 (SPM), Averaged Provincially.

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WI.

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WS.

Title:

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W4. Title: Index of Normalized Unit Load for Pulp and Paper Industry, Averaged Provincially, I_{nul} .

Caption: Nova Scotia and New Brunswick had the highest values, followed by Ontario, Quebec and Newfoundland. Note that the scale of this map is different from that of the two preceding.

W5. Title: Index of Total Load for Pulp and Paper Industry, Averaged Provincially, I_L .

Caption: The highest values of this index are found in Ontario, Quebec and British Columbia both having large pulp and paper industries.

W6. Title: Index of Normalized Unit Load for Petroleum Refining Industry, Averaged Provincially, I_{nul} .

Caption: Most Maritime Provinces have the highest values of this index, along with Manitoba. Most other provinces generally have relatively low values. Note that the scale for this index has changed from that of the four preceding.

W7. Title: Index of Total Load for Petroleum Refining Industry, Averaged Provincially, I_L .

Caption: The highest values are again in the Maritime Provinces, but in this case Quebec also has a high value.

W8. Title: Index of Total Load for Fish Processing Industry, Averaged Provincially, I_L .

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Caption: Quebec has the highest value, followed by British Columbia and Newfoundland. Due to lack of data, it was not possible to prepare a unit load index for this industry.

W9. Title: Index of Normalized United Load for the Chlor-Alkali Industry, I_{nul} .

Caption: Because of large decreases in the amount of mercury discharged into waters recently, the values of this index are uniformly low.

W10. Title: Index of Total Load for the Chlor-Alkali Industry, I_l .

Caption: Because of large decreases in the amount of mercury discharged into waters recently, the values of this index are uniformly low.

W11. Title: Index of Combined Total Load for the Five Sectors of the Effluent Water Index, I_l , Averaged over River Basins.

Caption: The highest values of this index are in river basins on the upper St. Lawrence River, on Lake Ontario, in northern Nova Scotia, western British Columbia, the Gatineau River in Quebec, and western New Brunswick.

W12. Title: Index of Trace Metals in Municipal Water Supplies, I_{TMC} .

Caption: This index is arranged on a basis of counties and census districts, rather than river basins. In general, this index is fairly low nationally. However, most provinces have at least one county in which the index falls into a moderate range.

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W13. Title: Index of Suitability of Water with respect to Turbidity,
 $I_{\text{turb av}}$, Averaged on a River Basin Basis.

Caption: The index is generally low east of the Manitoba - Ontario border, with a few exceptions. The southern and western parts of the Prairie Provinces have higher values of the index, but it again decreases west of the Rockies.

W14. Title: Index of Suitability of Water with respect to Turbidity,
 $I_{\text{turb av}}$, Averaged Provincially.

Caption: The western Provinces and the Northwest Territories have the greatest values of this index. The lowest are found in the Maritime Provinces.

W15. Title: Major Commercial Fishing Areas Closed or Under Fishing Limitations due to Mercury in Water.

Caption: Because of the nature of the information available, it was not possible to put it into the form of an index. However, the map can serve as background for the computation of the index of mercury in fish (see text). The largest closed or restricted areas are in Manitoba and Quebec.

L1. Title: Schematic Diagram of Land Quality Index.

L2. Title: Index of Maintenance of Forest Resources, I_{fm} , Averaged Regionally.

W3. Title:

Index of Suitability of Water with respect to Turbidity.
Turb av. Averaged on a River Basin Basis.

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Major Commercial Fishing Areas Closed or Under Fishing Limitations due to Mercury in Water.

Caption:

Because of the nature of the information available, it was not possible to put it into the form of an index. However, the map can serve as background for the computation of the index of mercury in fish (see text). The largest closed or restricted areas are in Manitoba and Quebec.

L1. Title:

Schematic Diagram of Land Quality Index.

L2. Title:

Index of Maintenance of Forest Resources, L₂. Averaged Regionally.

Caption: Saskatchewan and Manitoba have the highest value of the index, suggesting the lowest rate of regeneration of forest. The national average is relatively low.

Inside:
Caption: Only the forested areas are shown in colour.

L3. Title: Index of Forest Fire Damage, I_{ff} , Averaged Regionally.

Caption: The highest values of the index are in Manitoba and Saskatchewan. Again, the national average is relatively low.

Inside:
Caption: Only the forested areas are shown in colour.

L4. Title: Index for Damage due to Insects and Disease, I_{fp} , Averaged Regionally.

Caption: Areas outside of Ontario and Quebec tend to have very low values of this index.

Inside:
Caption: Enclosed areas on map indicate regions of spruce budworm infestation in 1972. (see comment in text). Only the forested areas are shown in colour.

L5. Title: Index of Combined Forest Environmental Quality, I_{for} , Averaged Regionally.

Caption: The Maritime provinces have the lowest value, followed by Ontario and Quebec. Saskatchewan and Manitoba have the highest value, due to the fire damage of 1970.

Inside:
Caption: Only the forested areas are shown in colour.

13. Title: Index of Forest Fire Damage, 1970, Averaged Regionally.
Caption: Inside: Only the forested areas are shown in colour.
Caption: Saskatchewan and Manitoba have the highest value of the index, suggesting the lowest rate of regeneration of forest. The national average is relatively low.

14. Title: Index for Damage due to Insects and Disease, 1970, Averaged Regionally.
Caption: Inside: Only the forested areas are shown in colour.
Caption: The highest values of the index are in Manitoba and Saskatchewan. Again, the national average is relatively low.

15. Title: Index of Combined Forest Environmental Quality, 1970, Averaged Regionally.
Caption: Inside: Enclosed areas on map indicate regions of spruce budworm infestation in 1970. (see comment in text). Only the forested areas are shown in colour.
Caption: Areas outside of Ontario and Quebec tend to have very low values of this index.

16. Title: Index of Combined Forest Environmental Quality, 1970, Averaged Regionally.
Caption: Inside: The Maritime provinces have the lowest value, followed by Ontario and Quebec. Saskatchewan and Manitoba have the highest value, due to the fire damage of 1970.
Caption: Only the forested areas are shown in colour.

L6. Title: Index of Overcrowded Dwellings in Metropolitan Areas, I_{cr}

Caption: Western cities generally have low values of this index, as did those in southern Ontario. The highest values were generally found in northern Ontario, Quebec and the Maritime Provinces.

L7. Title: Index of Probable Regions of Erosion, I_{er}

Caption: All of Eastern Canada has low values of the index. Most of western Canada has moderate values, with the highest ones falling in southern Saskatchewan and southern Alberta.

L8. Title: Index of Accessibility to National and Provincial Parks, I_{acc}

Caption: In this and the following two maps, the perception of certain environmental benefits or problems is shown (see text for details). The lowest values of this index are in those regions of British Columbia, Alberta and Saskatchewan near large national parks. Most of the rest of Canada has moderate values, with the highest values occurring in southern Ontario and Quebec. The contours in the coloured areas indicate the line where the values of the index is halfway between the maximum and minimum of that shade. For example, in the region where I_{acc} is between 0.4 and 0.6, the contour running through extreme western Ontario is that for $I_{acc} = 0.5$. This rule is also followed in Figures L9 and L10.

16. Title: Index of Overcrowded Dwellings in Metropolitan Areas, I_{ov}

Caption: Western cities generally have low values of this index, as did those in southern Ontario. The highest values were generally found in northern Ontario, Quebec and the Maritime Provinces.

17. Title: Index of Probable Regions of Erosion, I_{er}

Caption: All of Eastern Canada has low values of the index. Most of western Canada has moderate values, with the highest ones falling in southern Saskatchewan and southern Alberta.

18. Title: Index of Accessibility to National and Provincial Parks, I_{acc}

Caption: In this and the following two maps, the perception of certain environmental benefits or problems is shown (see text for details). The lowest values of this index are in those regions of British Columbia, Alberta and Saskatchewan near large national parks. Most of the rest of Canada has moderate values, with the highest values occurring in southern Ontario and Quebec. The contours in the coloured areas indicate the line where the values of the index is halfway between the maximum and minimum of that shade. For example, in the region where I_{acc} is between 0.4 and 0.6, the contour running through extreme western Ontario is that for $I_{acc} = 0.5$. This rule is also followed in figures 19 and 20.

L9. Title: Index of Closeness to Strip Mining, I_{SM} .

Caption: (See general statements about this type of map in the caption to Fig. L8). The high values of this index are localized in Alberta, Saskatchewan and New Brunswick. The rest of Canada generally has low to moderate values of the index.

L10. Title: Index of Closeness to High Sedimentation Areas, I_{sed} .

Caption: (See general statements about this type of map in the caption to Fig. L8). Highest values of the index were found in Alberta and British Columbia. The entire eastern half of the country has low values, which gradually increase towards the West.

M1. Title: Schematic Diagram of Miscellaneous Environmental Quality Index.

M2. Title: Pesticide Residues Intake, as compared to acceptable Daily Intakes.

Caption: Aldrin/dieldrin has the highest residue concentration in typical diets, as a percentage of international standards. However, this is still only about one-quarter of the standard. Other pesticides have a considerably lower percentage.

M3. Title: Index of Effect of Beta Radioactivity in Surface Air, $I_{dose a}$.

Caption: Most of the values throughout Canada are similar, with low readings on the West Coast and in the far north. The national average for this index is very low.

19. Title: Index of Closeness to Strip Mining, I_{SM}
Caption: (See general statements about this type of map in the caption to Fig. 18). The high values of this index are localized in Alberta, Saskatchewan and New Brunswick. The rest of Canada generally has low to moderate values of the index.
20. Title: Index of Closeness to High Sedimentation Areas, I_{sed}
Caption: (See general statements about this type of map in the caption to Fig. 18). Highest values of the index were found in Alberta and British Columbia. The entire eastern half of the country has low values, which gradually increase towards the West.
21. Title: Schematic Diagram of Miscellaneous Environmental Quality Index.
22. Title: Pesticide Residue Intake, as compared to acceptable daily intake.
Caption: Aldrin/dieldrin has the highest residue concentration in typical diets, as a percentage of international standards. However, this is still only about one-quarter of the standard. Other pesticides have a considerably lower percentage.
23. Title: Index of Effect of Beta Radioactivity in Surface Air, I_{dose a}
Caption: Most of the values throughout Canada are similar, with low readings on the West Coast and in the far north. The national average for this index is very low.

M4. Title: Index of Effect of Beta Radioactivity in Surface Air, $I_{\text{dose a'}}$
on a Quarterly Basis.

Caption: The low level of the first quarter of 1971 greatly increased
in the second, but it decreased with time so that the level
of the first quarter was less than that of the first.

C1. Title: Relative Contribution of the Four Components of the Environ-
mental Quality Index to the total Index I_{EQI} (on right).

Index of Effect of Beta Radioactivity in Surface Air, I dose at
on a Quarterly Basis.

Caption: The low level of the first quarter of 1971 greatly increased
in the second, but it decreased with time so that the level
of the first quarter was less than that of the first.

Relative Contribution of the Four Components of the Environ-
mental Quality Index to the total Index I_{EQI} (on right).



Fig. A2. Suspended Particulate Matter Index

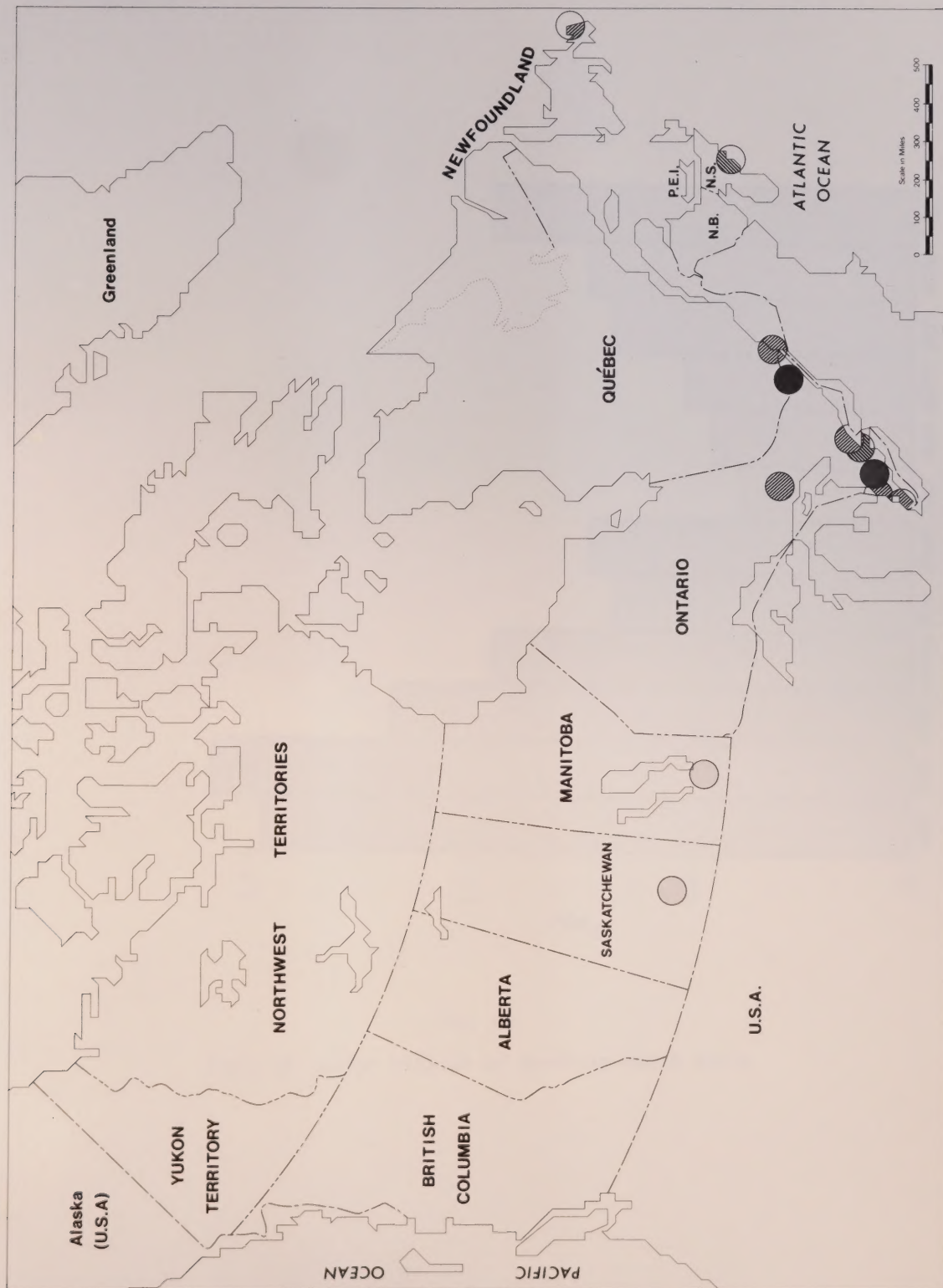


Fig. A3. Sulfur Dioxide Index

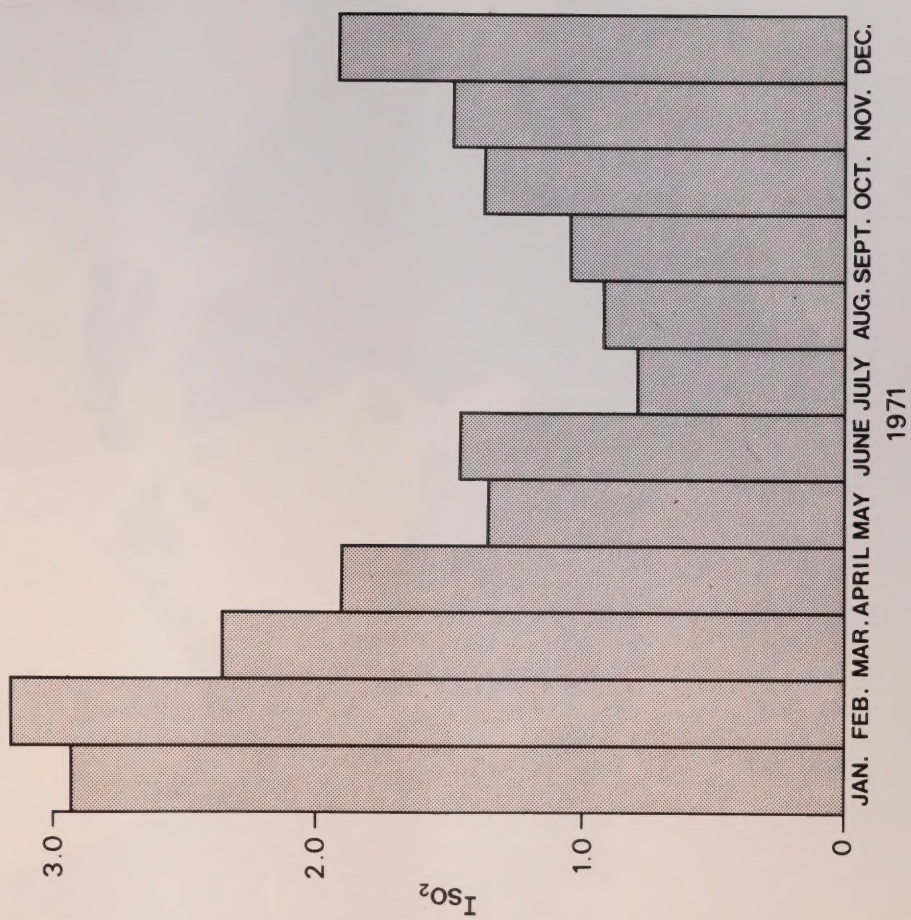


Fig. A5

Index of Sulfur Dioxide on Month-to-Month Basis



Fig. A7. Index of Inter-Urban Air Quality

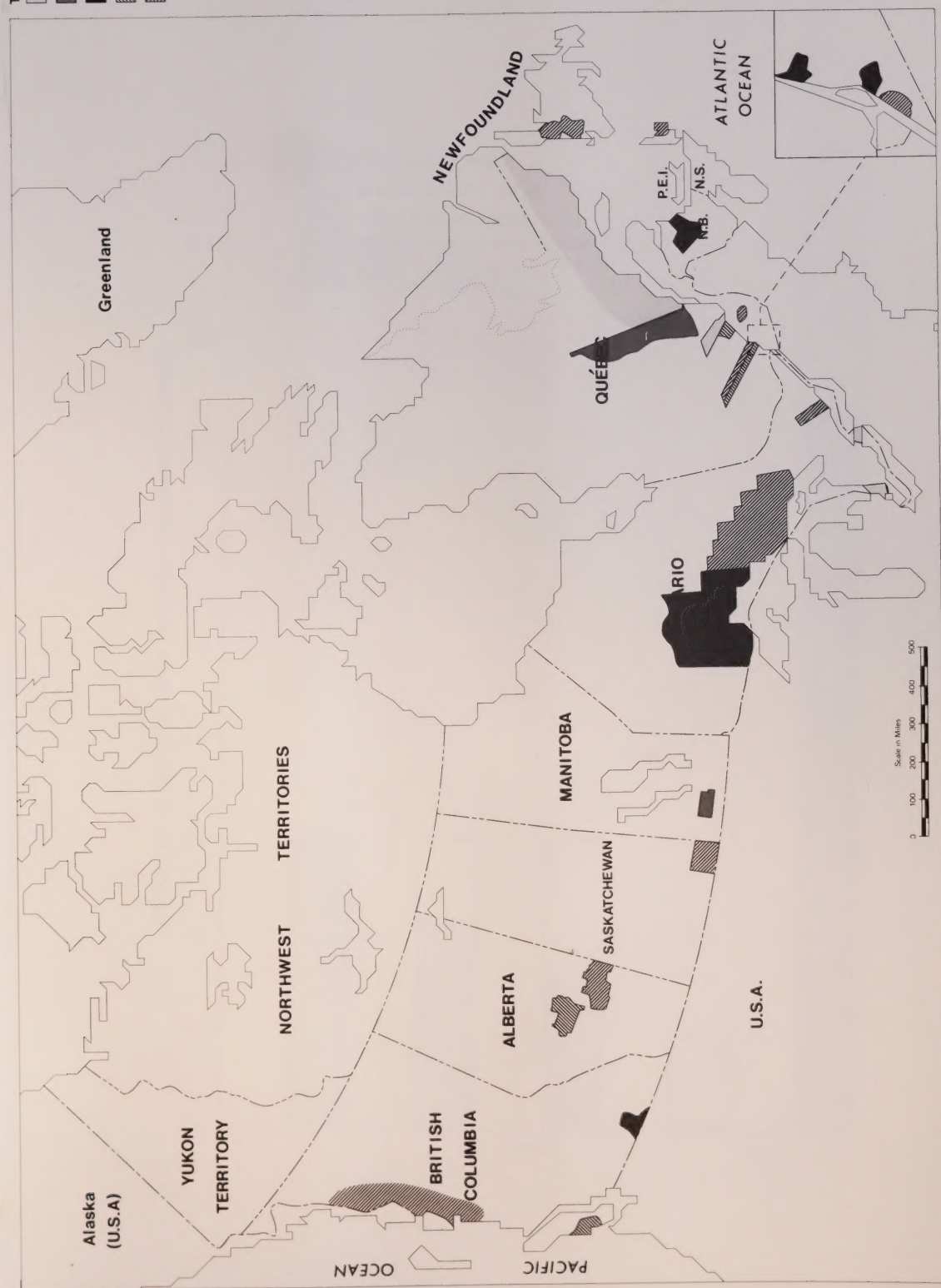
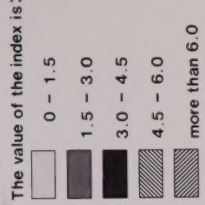


Fig. A9. Index of Industrial Emissions of Suspended Particulate Matter, averaged over counties

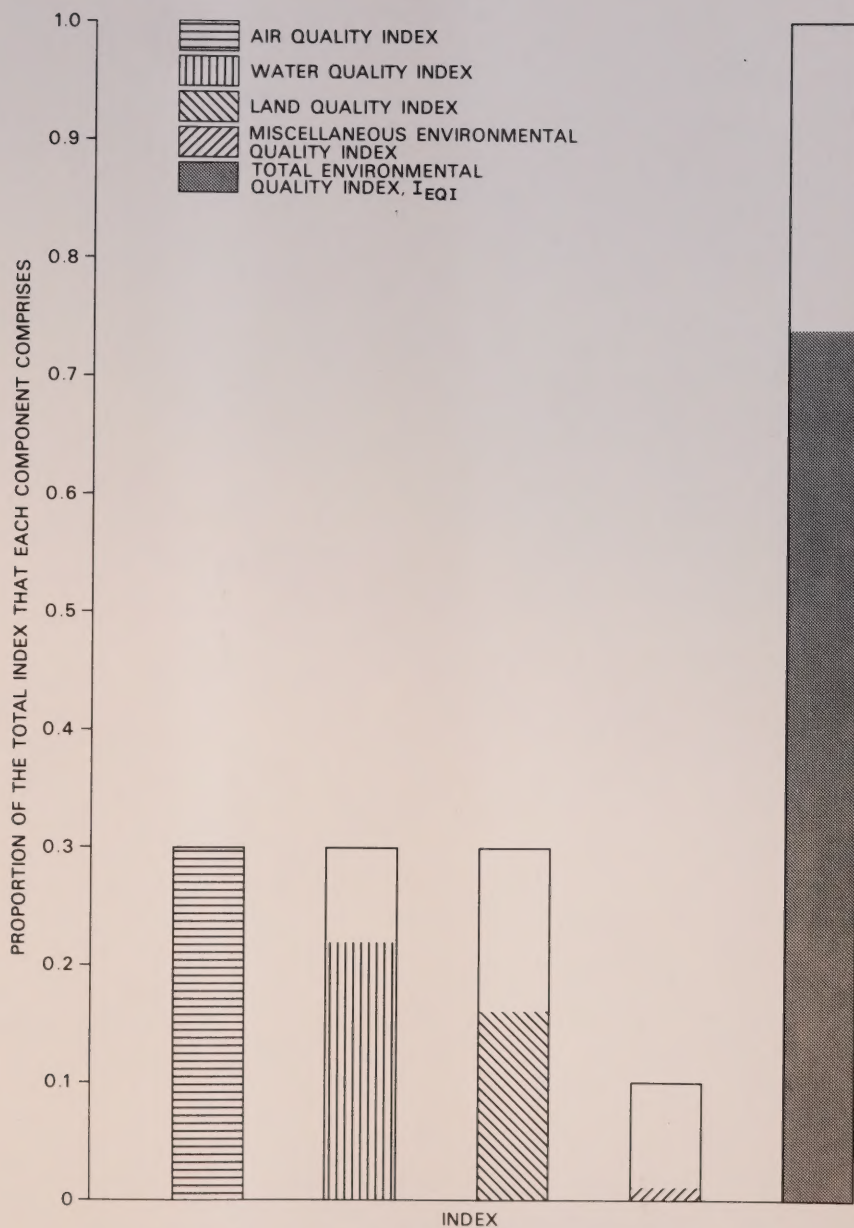


Fig. C1

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